TU Delft

Management of Technology

A Systematic Approach for Selection of Autonomous Inspection Technologies in Oilseed Industry

Master Thesis

Mr. Saket Shindikar

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A Systematic Approach for Selection of Autonomous Inspection Technologies in Oilseed Industry

A master thesis report submitted to Delft University of Technology in a partial fulfillment of the requirements of degree of

Master of Science

In

Management of Technology

Faculty of Technology, Policy, and Management

by,

SAKET SHINDIKAR

Student number: 5823625

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Graduation Committee

Chairperson, Second Supervisor: Prof. dr. ir. Genserik Reniers, Section 3S

First Supervisor: Ir. M.W. Ludema, Section T&L

External Supervisor: Wick Marcelissen (MSc), IT Management trainee, Cargill B.V

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Preface and Acknowledgements

Firstly, I would like to express my deepest gratitude to my parents, whose unwavering support and encouragement have been the bedrock of my academic journey. Their belief in my abilities and constant motivation provided me with the strength to persevere and pursue my dreams, even during the most challenging times. My achievements are truly built on the pillars of their love, faith, and sacrifices. I am especially indebted to my mother, Rajashri Shindikar, who has overcome numerous struggles in her own life to ensure that I could fulfil my dreams, particularly my studies here at TU Delft and in the Netherlands. As Principal of a high school, her dedication to education and her ability to balance her professional and personal responsibilities have always been a source of great inspiration to me. She has been my guiding light, instilling in me the values of perseverance and hard work. I would also like to express my heartfelt gratitude to my brother, Varun Shindikar, who, despite being in India, has been a constant source of encouragement and support. His unwavering belief in me and his moral support during both my successes and challenges have been indispensable throughout this journey. His presence in my life has provided me with the motivation to continue striving toward my goals. Additionally, I want to acknowledge my cousin brother, Saurabh Kulkarni, who was already in the Netherlands and played a key role in helping me navigate the challenges of living in a new country. His practical advice and support during certain phases of my journey have been incredibly valuable, and I am grateful to him for being there.

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- Saket Shindikar

The Hague, 2024

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Summary

Over the last decade, the global oilseed industry, which involves extracting oil from plant seeds like sunflower and rapeseed, has witnessed substantial growth driven by increased demand for renewable resources and advancements in agricultural and manufacturing technologies. This Master's thesis explores the integration of autonomous inspection technologies in the oilseed industry, aiming to address the challenges associated with traditional inspection methods. In Oilseed industry, oil is extracted from plant seeds such as sunflower, rapeseed, etc. The industry comprises of many complex production units set of operations, right from seed storage, seed preparation, seed extraction and oil refining. Timely inspection is essential to keep the uprightness of complex operational process to deliver a quality oil product. The inspection of industrial facilities is also important to manage safety around the oilseed plant. However, Traditional inspection methods in this sector, characterized by labor-intensive and error-prone processes, often lead to significant financial losses and compromised product quality. This gives an optimism for employing autonomous inspection technologies in the context of oilseed industry. Therefore, the primary objective with research questions of this master thesis is-***"To develop an assessment approach that supports strategic decision-making for industry leaders in the selection of optimal autonomous inspection technologies in oilseed processing."***

1. *What are the current processes and inspection points in oilseed processing, and how can they be described?*
2. *Which autonomous inspection technologies are potentially integrable into oilseed processing?*
3. *What are the assessment criteria for selection of applicable autonomous inspection technology(s) in the oilseed processing industry?*
4. *How can an autonomous inspection technology selection approach be systematically developed and validated for the oilseed processing industry?*

The thesis employs an exploratory research approach, utilizing qualitative methodologies such as case studies and interviews, which are especially effective for fields with less known study. This methodology not only facilitates comprehension of the difficulties in integration but also enables the identification of suitable prospects for using novel technology. The core methodology of this thesis is based on the double diamond model of design thinking, which consists of four distinct stages: Discover, Define, Develop, and Deliver as shown in Figure 1. Each step fulfils a strategic purpose by negotiating the intricacies of upgrading conventional industries with cutting-edge technology. During the Discover phase, a thorough examination of literature and contemporary technologies establishes the foundation, emphasizing the ineffectiveness of present inspection techniques and preparing for technical improvements. Transitioning to the Define phase, the study enhances its concentration by utilizing knowledge acquired from the discovery step to develop a precise problem description and establish the direction of the investigation. The development phase follows a progression from theoretical investigation to practical implementation, using Multi-Criteria Decision Analysis (MCDA) to assess the appropriateness of different technologies based on predetermined criteria. This phase concludes with a methodical approach to selecting technology, customized to address the requirements of the oilseed sector.

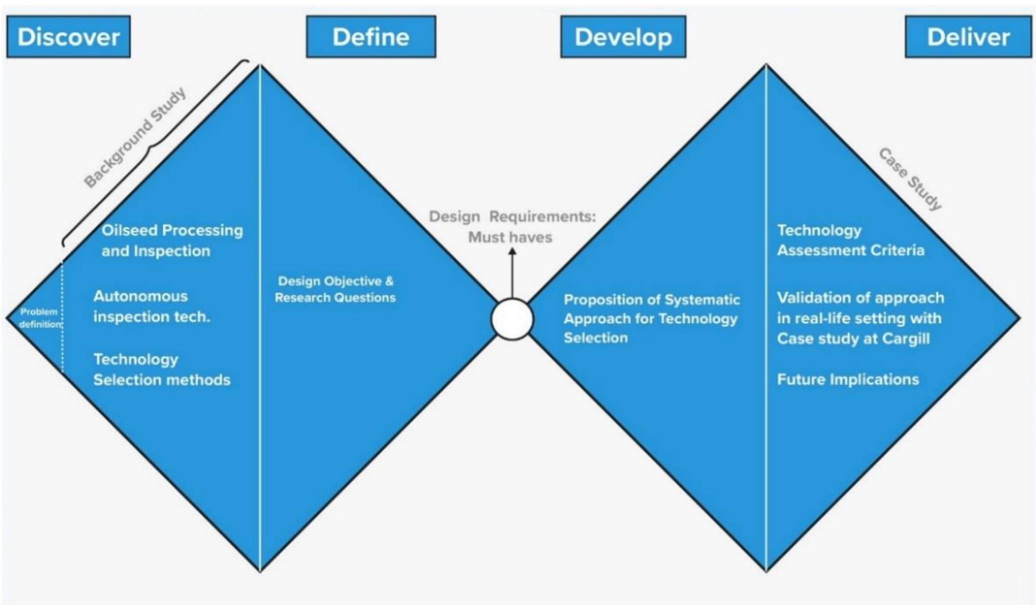

FIGURE 1. DOUBLE DIAMOND MODEL (AUTHOR'S OWN INTERPRETATION)

The background study consisted of four stages: first, in-depth understanding of the oilseed industry process; second, level of autonomy in technologies; thirdly, understanding of autonomous inspection technologies such as UAVs (Unmanned Aerial Vehicles) and UGVs (Unmanned Ground Vehicles); and finally, technology selection methods to review how technologies have been selected before. The importance of designing a well-organized approach is underscored to systematically incorporate autonomous inspection technology into the oilseed business. The investigation delineated the intricacies of oilseed processing, pinpointing steps that may be improved by technology interventions targeted at increasing efficiency and mitigating specific hazards, such as spoiling and extraction accuracy. It addressed the discovery of essential inspection use cases specifically designed to tackle distinct operational problems, which is crucial for the actual implementation and enhancement of these technologies.

The importance of Multi-Criteria Decision Making (MCDM) methods is emphasized, specifically when considering the Analytic Hierarchy Process (AHP) in relation to many criteria. This methodology guarantees the development of strategic, data-oriented decisions that synchronize technological selections with the unique requirements of the industry and the values of stakeholders. Consequently, it facilitates the effective acceptance and execution of autonomous inspection technologies in the oilseed sector. Analysis of articles on systematic approaches to technology selection was conducted to provide a set of design requirements. These requirements were then used to create a proposed systematic strategy for autonomous inspection technology in the oilseed industry, as indicated in the figure.

For the selection autonomous inspection technologies in the oilseed industry, the technology selection process is systematically outlined through eight steps. Initially, a clear definition of the problem identifies the need for automation to enhance precision, speed, and reduce human error at a lower cost. Subsequently, the extent of automation is established, considering the segments of the oilseed inspection process that can be mechanized. Comprehensive examination of the operational procedures enables the identification of areas that may be automated, therefore establishing precise scenarios for the implementation of technologies that can greatly enhance quality management. A comprehensive examination of the existing market offerings results in a compilation of prospective technologies. The selection process next applies Multi-Criteria Decision Analysis (MCDA), more precisely utilizing the Analytical Hierarchy Process (AHP) to rank criteria by comparing them in pairs and quantifying their weights using the eigenvector approach. The study proposes and modifies various process elements that facilitate a systematic and transparent approach to decision-making. Key activities such as the formation of teams, conducting initial meetings, interviews, and expert sessions are highlighted as the necessary activities to select the technology with this. approach. This methodical decision-making process concludes with the systematic evaluation of technological options, offering a distinct and practical result for industry executives to make well-informed choices on which technology to embrace, therefore assuring that solutions efficiently align with operational objectives.

The proposed systematic approach shown in figure 2. was validated by a comprehensive case study conducted at Cargill to assess the effectiveness and practical feasibility of the proposed technique. This practical implementation was meticulously designed in parallel with the procedural flowchart of the oilseed storage part of their operations, emphasizing the necessity for enhanced inspection techniques and a positive outlook on using new inspection technologies. The established business case was crucial in identifying six key use cases and demonstrating the potential of technology in monitoring conveyors, day tanks, seed cleaning equipment, tunnel areas, and asset integrity of all structures and storages. Next in the process of technological identification are Elios 3, Intel Falcon 8+, Taurob Inspector, Groundhog Pro, and ANYmal products. The systems were evaluated based on seven criteria: Usability, Financial Viability, Safety Standards, Operational Efficiency, Legal and Regulatory Compliance, Technical Proficiency, and Technological Maturity. These criteria were derived from empirical data obtained from interviews with experts from Cargill to ensure that the systematic assessment approach accurately reflected real industrial requirements and dynamics. These factors were subsequently included into the Analytic Hierarchy Process (AHP) to make the selection decision, which resulted in the choice of Elios 3. Elios 3 shown superior performance compared to its alternatives due to its ability to handle limitations and operate in complex situations, making it more appropriate for the operational issues at Cargill. The broad business case highlighted crucial areas of technology implementation and stressed the need of identifying technologies that can effectively and safely handle inspection of difficult-to-reach locations. This will help to minimize risks and enhance the dependability of the technologies in operation. The technologies, as examined in the case study, demonstrated that a carefully planned and evaluation-driven approach for selecting technology can be theoretically developed and implemented effectively for this oilseed processing sector. This validation conducted at Cargill has verified the methodology's applicability and performance, marking a significant achievement in the implementation of active inspection technology.

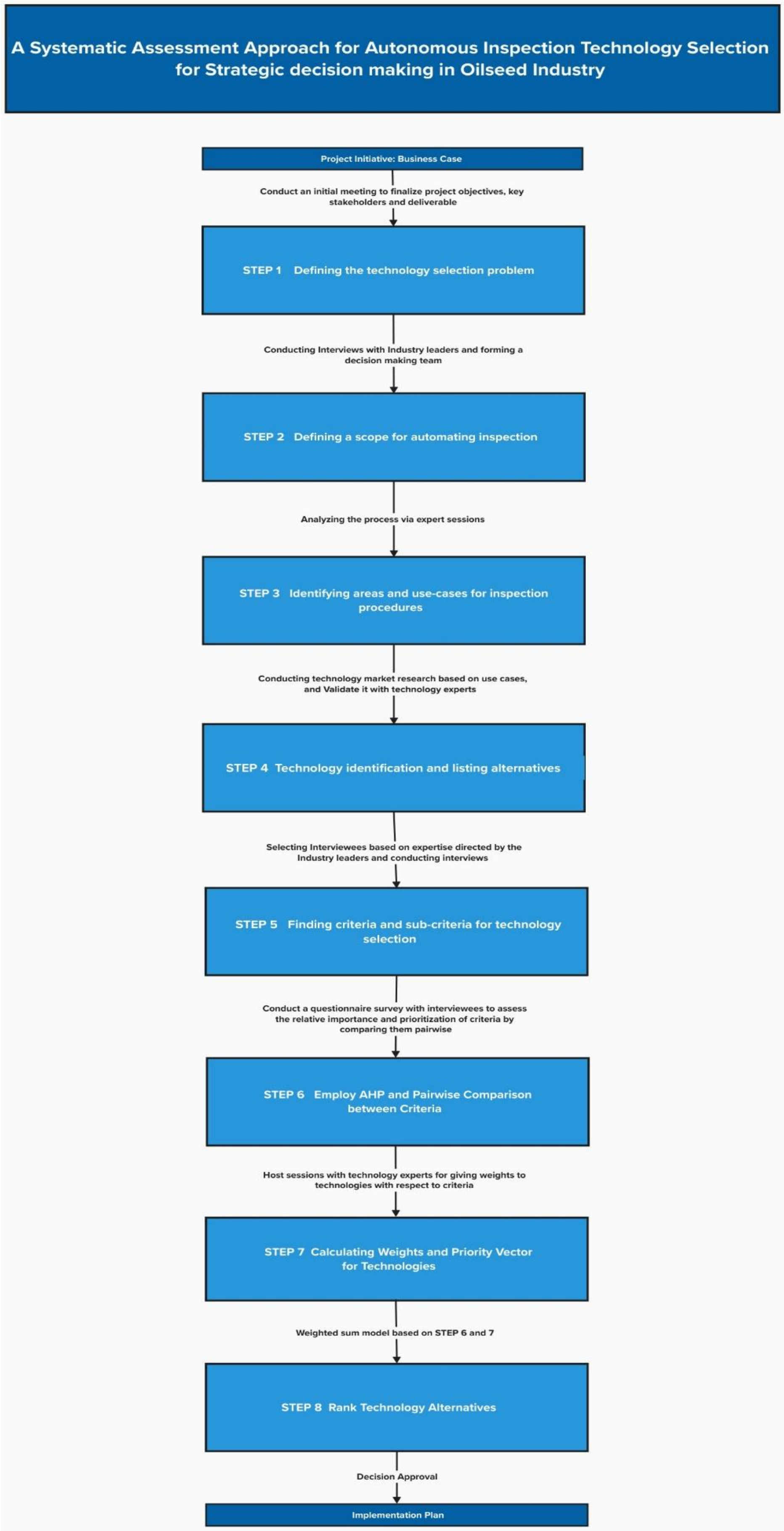

FIGURE 2. SYSTEMATIC ASSESSMENT APPROACH

List of Figures and Tables

Figures

Figure 1. double diamond model (Author’s own interpretation) 7
Figure 2. SYSTEMATIC ASSESSMENT APPROACH 9
Figure 3 Thesis Outline 5
Figure 4. Oilseed Plant Overview (author's own interpretation) 11
Figure 5. Oil Refining steps 14
Figure 6. Types of Autonomous Inspection Technologies 16
Figure 7 Intel Falcon 8 plus by Cyberhawk 18
Figure 8. Elios 3 by flyability 18
Figure 9. MosCoW Approach (author's own interpretation) 23
Figure 10. SYSTEMATIC ASSESSMENT APPROACH 27
Figure 11. Research scope 30
Figure 12. Seed Storage Area: Cargill (author's own interpretation) 31
Figure 13. Elios 3 33
Figure 14. Intel Falcon 8+ 33
Figure 15. Taurob Inspector 34
Figure 16. Groundhog Pro 34
Figure 17. ANYmal 34
Figure 18. CODE TREE 39
Figure 19. AHP HIERARCHY 40
Figure 20. Systematic Assessment Approach 46
Figure 21. Approach Part A 47
Figure 22. Approach Part B 48
Figure 23 Initial codes from atlas 65
Figure 24 Code groups from atlas 65
Figure 25 Criteria description 66
Figure 26. Sensitivity Analysis 1 75
Figure 27. Sensitivity Analysis 2 75

Tables

Table 1 Interviewees 35
Table 2 Pairwise Comparison Matrix 41
Table 3 Usability 42
Table 4 Financial Viability 42
Table 5 Safety Standards 42
Table 6 Operational Efficiency 43
Table 7 Technical Capability 43
Table 8 Legal Compliance 43
Table 9 Technology Maturity 44
Table 10 Technology Ranking 45
Table 11 Interviewee list and information 64

Contents

1. Introduction **1**

1.1 Autonomous Inspection in Oilseed industry 1

1.2 Problem Statement 2

1.3 Relevance 3

1.4 Design Objective and Research Questions 4

2. Project Methodology **6**

2.1 Research Design: Exploratory 6

2.2 Project Approach: Double diamond approach in design thinking 6

2.3 Research and data collection methods 8

2.4 Data Analysis 10

2.5 Research Quality 10

2.6 Conclusion of Project methodologies 10

3. Background study **11**

3.1 Oilseed processing and Inspection 11

3.2 Concept of Autonomy in Inspection technology 16

3.3 Autonomous Inspection Technologies in Oil Industry 17

3.4 Techniques for Technology Selection 19

4. Systematic Assessment Approach **21**

4.1 Background Study Analysis and design requirements foundation 21

4.2 Designing systematic approach 22

4.3 MosCoW Prioritization method for design requirements 23

4.4 A Systematic Assessment Approach for Autonomous Inspection Technology Selection in the Oilseed Industry 24

4.5 Conclusion Chapter 4 28

5. Empirical findings and Case Study **29**

5.1 Introduction 29

5.3.1 Cargill Business case (problem definition and research scope (STEP 1 and 2) 29

5.3.2 Process and inspection activities (Seed storage area at Cargill) (STEP 3) 30

5.3.3 Technology identification and listing alternatives (STEP 4) 33

5.3.4 Criteria for Technology selection (STEP 5) 35

5.3.5 Employ Analytical Hierarchy Process (STEP 6,7,8) 40

5.4 Conclusion chapter 5 49

6. Conclusion, Recommendations and Discussions **50**

6.1 Conclusion 50

6.2 Generalizability of Study 52

6.3 Limitations 52

6.4 Recommendations 53

6.5 Discussions 53

6.5.1 Double diamond implications 53

6.5.2 Managerial Implications 54

References **55**
Appendix 1 .... **61**
Appendix 2 .... **63**
Appendix 3 .... **65**
Appendix 4 .... **67**
Appendix 5 .... **74**
Appendix 6 .... **75**

1. Introduction

1.1 Autonomous Inspection in Oilseed industry

1.1.1 Oilseed Industry's and Inspection

The past ten years have witnessed a significant growth in the global oilseed industry, which has increased its importance in the agriculture based and manufacturing sectors through a combination of factors. Technological developments in manufacturing, diminishing fossil fuels supplies, and increasing demand for renewable sources of energy are the major forces behind this phenomenon. Thus, this industry has become recognized as an important player in global market. Oilseeds are plants that contain high levels of oil thus being critical source for plant-based oils production. This market has experienced massive growth with estimates suggesting 5.1% annual growth between 2020 and 2026 (Plant-based Oils Market Size and Business Opportunities, 2021). The upward trend mirrors how competitive consumer market and industrial applications drive the oilseed sector. There are a variety of plants that include sunflower, rapeseed, cottonseed, palm, and olive that their seeds can be used to extract oil from them. To produce plant-based oils, this is often the main method employed. These types of oils have found applications in many products including industrial lubricants, cosmetics, and biofuels and others.

The increasing demand for plant oils makes the requirements for well-operating industrial infrastructure in oilseed plants to be of ultimate importance ever before. The manufacturing process is a demanding task that involves the extraction of oil from seeds and requires extensive attention to detail to attain optimal yields and maintain high product quality. Each instance of inefficiency or error during this procedure can lead to significant financial losses, compromised quality of the product, and even failure to comply with regulations. Effective maintenance of an efficient industrial infrastructure can be achieved by implementing stringent inspection processes. Inspections play a crucial role in verifying that all elements of production adhere to necessary criteria, including the condition of equipment, the quality of raw materials, and the final products manufactured. Their role is to facilitate the early identification of issues that may arise during operational disruptions, minimize waste, and ensure the safety of personnel. However, traditional inspection methods have several drawbacks that limit their effectiveness in present-day oilseed plants. These methods frequently rely on human labor which is not only time-consuming but also subject to errors. Besides, the inspection sites are usually dangerous areas where workers can be exposed to risks. This is where the optimism of employing autonomous inspection technologies rises, offering a promising solution to the challenges because of inspection faced by the oilseed industry

1.1.2 Emergence of Autonomous technologies

The introduction of self-governing inspection technologies is significant for industries that rely heavily on regular and conventional inspections. These technologies are expected to revolutionize how oilseed plants conduct inspections using advanced robotics, artificial intelligence (AI) and intelligent systems. Autonomous inspection systems have been designed in a way that they can operate independently or with minimal human intervention, which makes them ideal for situations where traditional inspections would be difficult or unsafe. Visual inspection, thermal imaging, vibration analysis and data collection are among the many functions that these systems can be programmed to perform. Therefore, oilseed plants can achieve much more accuracy and uniformity in inspections by automating these processes hence improving operational efficiency as well as safety. Another advantage of autonomous inspection technologies is their ability to work continuously without breaks or shift changes being required. This technology implementation enables the production process to be under constant monitoring empowering plant operators find out potential anomalies quicker than later while taking appropriate steps to rectify them promptly.

The future of the oilseed industry, indeed, of the broader space of manufacturing industry, is dependent on conscientious selection and integration of autonomous technologies. Only with due care in their selection and implementation will oilseed plants be able to create better inspection methodologies, enhance operational efficiency, and retain full compliance with regulatory requirements. This thesis points revolves around selecting and adopting independent inspection technologies, increasing not only work processes but also data-driven decision-making. Strategic choice of fit-for-purpose technologies will enable the oilseed sector to remain at the frontline in building a future full of higher efficiency, safety, and sustainability.

1.2 Problem Statement

Within multiple industries such as manufacturing and technology, inspections are of crucial significance in ensuring compliance to legal requirements and maintaining the quality of final products (Milica Babic, 2021). Inspections are crucial for optimizing supply chains, as they facilitate the identification of flaws, guarantee the quality of products, and uphold safety regulations. Accurate and timely inspections are crucial for sustainable infrastructure and operational efficiency since they minimize system downtime, lower maintenance expenses, and enhance workforce productivity (Zavarce, 2023). Given the complex equipment and high-pressure conditions involved in the extraction and processing of oils from seeds in the oilseed industry, regular inspections are crucial to detect potential problems before they become major problems, so assuring seamless and uninterrupted operations. Nevertheless, conventional inspection techniques using human labour in the oilseed sector pose numerous difficulties. The conventional methods, being labour-intensive, demand significant human resources and time, resulting in high costs and inefficiency. In addition, these techniques can endanger the safety of workers, particularly in dangerous settings where oilseed processing entails elevated temperatures, limited areas, and contact with chemicals. Operator workers assigned to conduct inspections under such circumstances are exposed to hazards of accidents and injuries. Furthermore, the ability of human inspectors to access specific plant areas may be restricted, so impeding the comprehensiveness and efficiency of inspections. The potential oversight of critical areas may result in an elevated risk of undetected flaws or maintenance requirements, so increasing the likelihood of equipment failure and unforeseen periods of inactivity.

Human errors pose serious issues linked to conventional inspection techniques in the oilseed sector. Even highly skilled inspectors are prone to errors, which can include overlooking flaws or making inaccurate evaluations of equipment specifications. These errors can lead to substantial financial losses caused by unexpected periods of inactivity, malfunctions of equipment, or even disastrous incidents. Human errors in inspection tasks can have significant financial implications in industries such as oilseed processing, where precision and accuracy are very significant (Ballon, 1982). The analysis on toxic gas leakage in an oil industry revealed that the accident was primarily caused using inferior equipment, a lack of safety culture, and insufficient inspection of recently acquired equipment (Fakhradin Ghasemi, 2022). Moreover, the oilseed industry encounters labour issues that worsen the challenges in carrying out efficient inspections. The labour-intensive nature of conventional inspections often necessitates an extensive workforce, which can be challenging to sustain, particularly in areas experiencing labour shortages or high rates of employee turnover. Furthermore, with a sector is facing the challenge of an aging workforce, resulting in retirements and a depletion of skilled personnel gives rise to an optimism of intense need for more effective inspection techniques that decrease dependence on human work and reduce the possibility of human mistakes.

Insufficient inspections and maintenance processes can result in severe repercussions within the oilseed sector. Just as in the petroleum industry, where inadequate maintenance has resulted in major accidents, the oilseed sector is susceptible to comparable occurrences if inspections are not comprehensive and prompt. Specifically, within the petroleum sector in the Netherlands, numerous accidents have taken place, with around 38% of these being ascribed to pipe failures and chemical leaks resulting from inadequate inspection and maintenance measures (Tokarski, 2013). Insufficient inspections of processing equipment in the oilseed industry can result in contamination, diminished product quality, and safety risks, all of which can have significant financial and reputational ramifications for oilseed processing enterprises. The presence of these difficulties creates a significant motivation to enhance the efficiency of inspection procedures in the oilseed sector. The constraints associated with conventional human inspection methodology underscore the necessity for more sophisticated alternatives, such as autonomous inspection technologies. These technologies have the capability to enable consistent, precise, and uninterrupted inspections, so decreasing the dependence on human labour and mitigating the hazards linked to human fallibility. Through the implementation of autonomous inspection systems, the oilseed industry can optimize operational efficiency, bolster safety measures, and minimize maintenance expenses, so guaranteeing the ongoing prosperity and durability of their activities.

In conclusion, the oilseed industry encounters substantial obstacles in maintaining streamlined and successful inspection procedures. The conventional techniques are characterized by their high labour requirements, susceptibility to human mistakes, and potential safety hazards, which renders them less suitable for the requirements of contemporary oilseed processing. Automated inspection technologies, when adopted, present a promising solution to these issues by equipping the industry with the necessary tools to enhance inspections, increase operational efficiency, and guarantee the safety and quality of their products. The integration of autonomous solutions, such as robots, presents an opportunity to optimize inspection processes by automating low-value repetitive tasks and improving efficiency. This automation will most likely to replace these tasks than their core jobs (Sungsup Ra, 2019). They offer advantages such as enhanced accessibility to hazardous environments, excellent accuracy in data collection, and its capability to store and analyze data systematically for actionable insights. By leveraging autonomous inspection technologies, organizations can mitigate the barriers associated with the human workforce inspections, including labor costs, workforce shortages, and compromised operational efficiency. Furthermore, autonomous solutions have the potential to enhance data management by streamlining information storage and analysis, thereby bridging existing information gaps, and enabling informed decision-making (Zavarce, 2023).

From an industry point of view, the organization should select and allocate resources to a technology sector that offers a comparative advantage among several technological options, considering several economic, technical, and social factors in a complex environment (Yu, 1998). Due to the various factors, technology selection is a complex challenge that involves multiple criteria in the decision-making process (Gregory M. L., 1997). While there are papers available approaches on technology selection which such as hybrid selection model for high-tech OLED system (Yung-Chi Shen, 2010) .There are several papers available which are close to robot selection models or decision support systems, but there While there is notable lack of any literature availability for technology selection in the context of oilseed industry and this industry will go through a transition where Industry 4.0, will have interconnected computers, advanced materials, and intelligent machines which will work together and exchange information responding to their environment. Eventually, they will make decisions independently, requiring minimal human intervention (Gilchrist, 2016). Hence with this emergence of industry 4.0 and autonomous technologies, there will a requirement of more systematic, data-driven and feasible approach to guide decision makers to make informed choices while selecting potential inspection technology. Therefore, the thesis proposes a systematic assessment approach to technology selection through strategic decision-making and the use of multi-criteria decision-making methodology in oilseed processing.

1.3 Relevance

1.3.1 Academic relevance

Although there is an enormous corpus of academic literature on problems concerning the integration of autonomous inspection technologies into the oil and petroleum industries and a detailed procedural study of extraction of seed oil, there is a wide gap in literature about the actual use of oilseed inspection technologies within the oilseed industry. This under-researched area becomes a very interesting relevance for this research. There is a lack of focus on decision-making in terms of selection of technology within oilseed industry. The objective of this thesis is, therefore, to provide a holistic approach to technology selection and analysis. Critical factors necessary in the context of oilseed industry will identify steps required for technology's selection, supported by a qualitative and partial quantitative research method. This methodological approach will respond to a demand in this sector, bringing a set of relevant views to the academic and industrial worlds. This will make this relatively ignored area better understood, with its approach being systematic and strategic for the choice and use of technologies that can be adopted by the oilseed industry.

1.3.2 Management of Technology (MOT) relevance

The thesis on autonomous inspection in the oilseed industry integrates with the Management of Technology programme by investigating the strategic implementation of technology to improve operational efficiency and ensure compliance. It employs a multi-criteria decision-making framework, exemplifying MOT principles and offering solutions to meet industry-specific challenges. It also focuses on answering the questions which are addressed by delft university of technology's MOT programme. (MOT, n.d.)

1. What technologies do we need and when?

This thesis nurtures the understanding of the adoption of independent inspection technologies in the oilseed industry regarding context and timing for effective optimal use. This thesis contributes a great deal to the strategic process of knowing when the best time will be to introduce technology by underlining critical times during industrial operation—a call for independent inspection technology integration.

2. Do we procure the technology we need with our own research capabilities, in collaboration with outside parties, or by acquiring it or licensing it from others?

The thesis presents in detail a structured approach to technology sourcing and demonstrates how an organization can make use of its research competencies but also take advantage employing new technologies. This holds the full adoption approach that fits both the internal competencies and the potential of the market.

3. How can we use the abundant technological opportunities to affect our mission, objectives, and strategies?

This thesis has, in turn, been able to show how organizations such as Cargill can improve operational efficiency and regulatory compliance for competitive advantage purposes by using autonomous inspection technologies. Here, the strategic use of technology promotes better decision-making and operational flexibility, which is consistent with the organizational mission and longer-term strategic imperatives.

The detailed information on how the MOT courses relate to this thesis is in Appendix.

1.3.3 Practical relevance

Practical relevance of this thesis comes on autonomous inspection technologies, mainly in operations optimization within the oilseed industry, and an unbroken process in keeping standards of safety. Automation will significantly reduce human reliance, decrease exposure to human beings, less exposure to dangerous situations, and foster increase in accuracies of operational inefficiencies or failure. This change not only makes the entire process much safer but also enhances the accuracy and reliability of the inspections. While the thesis is a blend of various methodologies, the use of case study and blending it with pragmatic approach generates an output of thesis as more realistic, practical, and one step closer to industrial needs.

The thesis goes on to give a detailed approach for evaluation and selection of appropriate autonomous technologies whose design has specifically met the oilseed industry operational requirements. Such a systematic procedure will help leaders of the industry make informed decisions on technological investments that improve efficiency and quality of the product.

The implementation of such advanced technologies ensures that oilseed processing companies remain competitive in an agricultural market characterized by extremely fast technological development. The approach brings about data-based insights into optimization of operations and instant adjustments to updated conditions that are issued either from the market or regulatory authorities. The immediate and far-reaching advantages of integrated autonomous inspection technologies form the basis for this research on underpinning industrial potential for innovation in the oilseed sector. This presents to the objectives that this research aims to achieve.

1.4 Design Objective and Research Questions

The design objective of this Master Thesis is given as follows:

"To develop an assessment approach that supports strategic decision-making for industry leaders in the selection of optimal autonomous inspection technologies in oilseed processing."

This method aims to evaluate technologies through a systematic assessment approach that incorporates oil industry-specific criteria, ensuring that the selected technology aligns with operational requirements and enhances efficiency. The assessment approach is structured into the following sub-objectives to address the complex criteria for technology selection:

1. *Analysis of Current Oilseed Processing:* Conducting a detailed analysis of existing oilseed processing methodologies, with a focus on not just describing process and seed journey but identifying critical inspection points within the process.

2. *Analyse compatible inspection technologies:* Identifying autonomous inspection technologies in the process of oilseed production, based on technical feasibility and compatibility with the working conditions.

3. *Development of Criteria for technology assessment:* Formulating a set of criteria that would be relevant in the context of oilseed processing for the assessment the different autonomous inspection technologies.

4. *Development and validation of an assessment approach:* Developing a structured process to assess the applicability of autonomous inspection technologies and its selection in oilseed processing and then validating it through case studies with a view to the efficiency and practicability.

Based on the research deliverable of assessment method, there are research questions that originate are stated below:

1. What are the current processes and inspection points in oilseed processing, and how can they be described?

2. Which autonomous inspection technologies are potentially integrable into oilseed processing?

3. What are the assessment criteria for selection of applicable autonomous inspection technology(s) in the oilseed processing industry?

4. How can an autonomous inspection technology selection approach be systematically developed and validated for the oilseed processing industry?

The pragmatic methodology is aimed at making sure that a proposed systematic assessment approach does not merely rest on theoretical frameworks but is compatible with concrete operational needs and challenges that are relevant to the oilseed processing industry. It first accounts for actual applicability, in which criteria particular to the industry are combined: unique raw material characteristics, processing conditions, and key steps of inspection. The paper, therefore, offers practical and implementable guidelines on the selection of standalone inspection technologies that are technically feasible and realistic in their applicability. The methodology will be validated and refined based on operations in a case study. This case study will be bettered and will include inputs from industry experts, including many inputs from professionals working with Cargill, to ensure that the developed methodology has its roots in current industry norms and challenges. The methodological approach will be demonstrated and evolved by its application until such time as the assessment Framework is a robust and emerges as a strategic tool for industrial decision-makers. The detailed project methodology to address all the research questions is stated in the next chapter.

1.5 Thesis outline

The following figure 3. shows an overall thesis outline for the report.

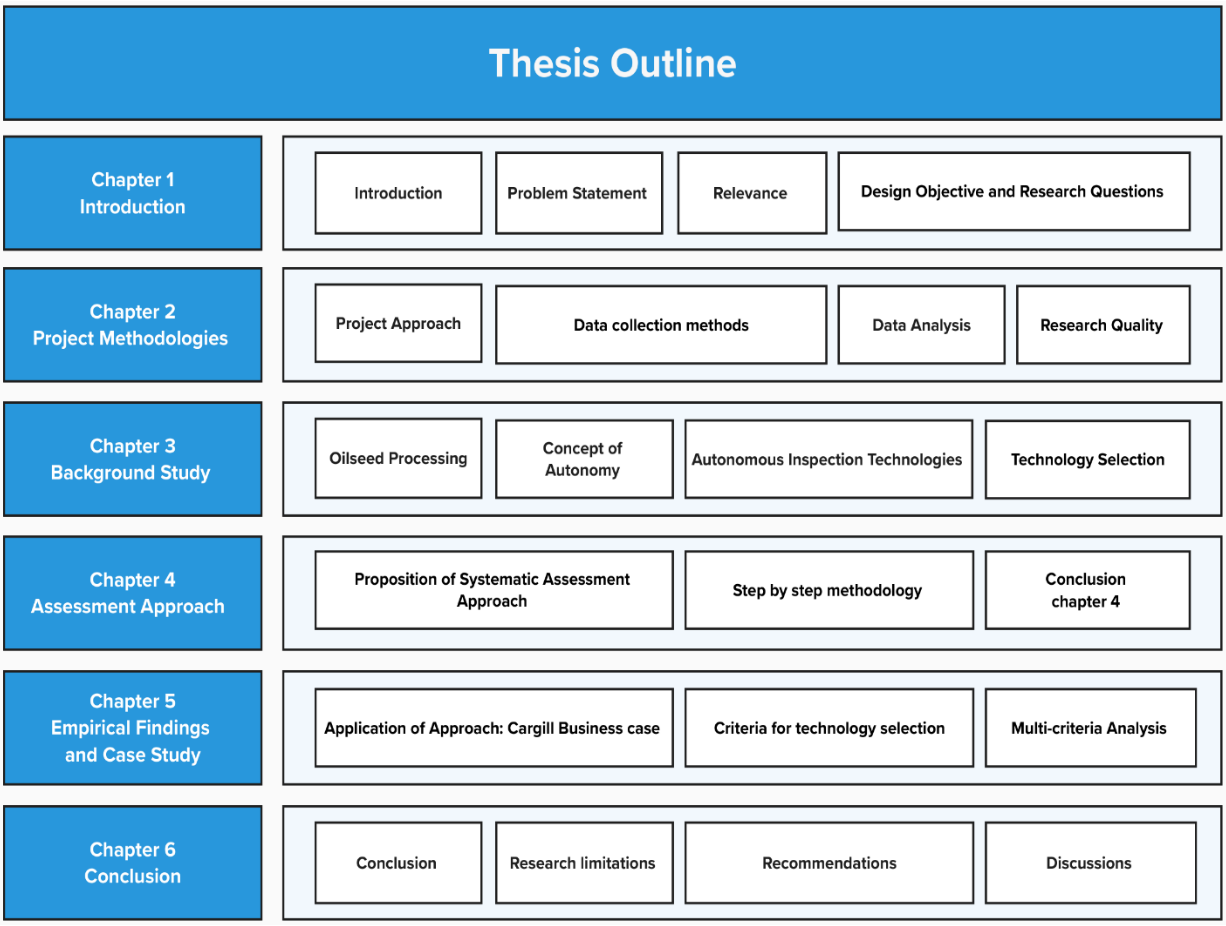

FIGURE 3 THESIS OUTLINE

2. Project Methodology

2.1 Research Design: Exploratory

Exploratory studies are especially useful when little is known about the phenomenon being studied (Sekaran, 2016). With the use of flexible and adaptable qualitative techniques like case studies and interviews, this kind of research enables researchers to delve deeply into the subject matter. The ability of an exploratory design to create and improve a methodology or approach considering preliminary results is what determines which design to choose. This strategy is essential for developing a thorough understanding in areas where prior knowledge is nonexistent, allowing researchers to develop more accurate study frameworks and hypotheses as they gain further knowledge.

2.2 Project Approach: Double diamond approach in design thinking

The project approach in this research is based on the double-diamond methodology in design thinking. As the research design is exploratory, the design thinking is as process itself is explained as exploratory in nature (Brown, 2009) The design thinking as a broad term is regarded as a valuable tool for businesses seeking to innovate, it helps to improve the coordination between business strategies and advancements in products and services (Martin, Design thinking: Achieving insights via the "knowledge funnel", 2010) (Martin, The Innovation Catalysts, 2011). Design Thinking is a methodology that provides guidance on how to address complex business challenges. The sequential phases of a standard Design Thinking process entail cultivating a profound understanding of end-users, redefining the problem domain, generating concepts, fabricating prototypes, and executing tests (Groeger, 2014). The rationale for selecting design thinking over conventional design approaches is its simplicity as aims to summarize this process and present it as a technique for innovative problem-solving that can be broadly accepted by individuals who may not have a background in design (Groeger, 2014).

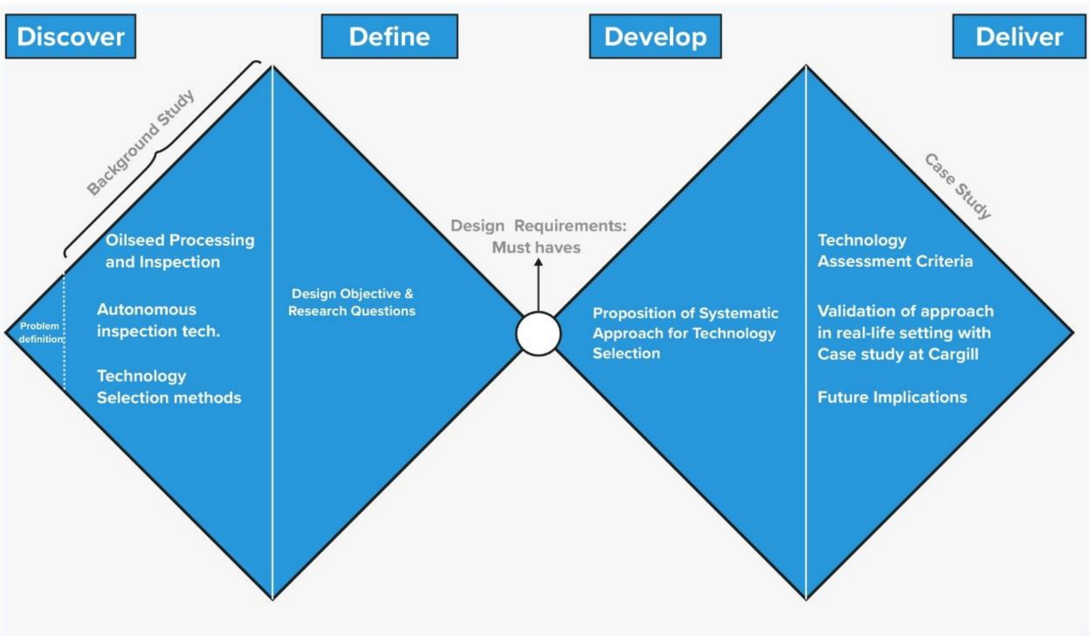

FIGURE 4. DOUBLE DIAMOND MODEL (AUTHOR'S OWN INTERPRETATION)

The design thinking process initiates with a divergent phase, during which new opportunities are investigated. This is then followed by a convergent phase, where the findings are carefully examined and combined to form different opportunity areas. (U.K, Design Council, 2011). The Double Diamond process model (in figure 4.) was developed by British design council to structure an approach which is generalisable for most design thinkers (U.K, Design Council, 2011). It consists of four distinct phases; discover, define, develop, and deliver. The approach is also based on simultaneous divergent-convergent thinking. The first phase of divergent thinking, the discovery phase, consists of understanding of problem with the observations with the help of background study then carefully structuring & planning it into the research. The second phase of first diamond defines the research into a design objective in a form of convergent thinking. The third phase with second double diamond is again a form of divergence which creates solution space of the problem which is a result of consistent brainstorming of ideas, creating multiple iterations and testing of the solution(s). The final quarter, the deliver phase, concludes with testing and delivering of design (U.K, Design Council, 2011).

First Diamond: Discover and Define

The first stage of the double diamond design approach, is dedicated to comprehensively understanding and investigating the problem space via introducing the research area and generating a problem statement. This preliminary phase of the thesis on autonomous inspection technologies in oilseed processing further includes the gathering of comprehensive background knowledge through a literature study. Primary activities include analysing existing oilseed processing techniques, identifying inspection methods, and reviewing technology selection approaches that have the potential to change inspection practices. The objective is to comprehensively gather a range of perspectives and potentialities, which entails interacting with multifaceted sources of information, including industry reports and academic research. Progressing from the stage of discovery to the stage of definition, this phase refines the focus by utilizing previous insights. The initial phase establishes the groundwork for subsequent phases by explicitly delineating the design objectives and proposing four research questions.

Second Diamond: Develop and Deliver

The Develop stage is defined by a transition from theoretical to practical considerations, with the goal of generating solutions that align with the specified objectives. The second diamond begins with analysis of background study, as it works as one of the foundations for design. This involves a methodical approach to assessing various technologies, considering the requirements of oilseed processing industries. Methods such as multi-criteria decision analysis are used to evaluate the applicability of various technologies, ensuring that the solutions are not only empirically valid but also practical in real-life situations. The last phase involves finishing the solution and preparing it for practical implementation. By means of real-life case studies, such as the one conducted at Cargill, the thesis aims to validate the systematic assessment approach for selection of autonomous inspection technologies. This phase evaluates the practical implementation of the theoretical model created in the earlier stage and performs the step-by-step procedure. Lastly, the design concludes formulating conclusions and deliberating on the future recommendations of the research.

Diamond Intersection: MosCoW Method for design requirements

At the point where the Discover and Define stages meet the Develop and Deliver stages, the MosCoW approach is used to give priority to the requirements that were specified during the Define phase. By classifying requirements into "Must have," "Should have," "Could have," and "Won't have," this approach ensures that the design and development stages focus on the most crucial elements necessary for a successful implementation (Barker, 1994). The approach is opted for its agility as it clearly states the design requirements and it is easier for stakeholders to understand the significance of each requirement (The MoSCoW Method, n.d.)

The MosCoW approach in this thesis facilitates the prioritization of the key aspects of autonomous inspection technologies for oilseed processing, as well as those that are desirable but not essential, and optional or beyond the scope. This systematic methodology facilitates effective distribution of resources and guarantees that the project stays concentrated on providing the highest possible value.

2.3 Research and data collection methods

2.3.1 Literature study

The literature review for this thesis commenced by conducting a comprehensive search using Google Scholar to collect initial information, such as industry reports, research papers, books, and news articles, on oilseed processing and the incorporation of autonomous inspection technologies. These initial sources established a fundamental comprehension of the present patterns and advancements in the field. Subsequently, the academic databases provided by TU Delft, namely Google Scholar, Scopus, Science Direct, and IEEE were referred, to strengthen and expand the exploration for scholarly articles and research papers. The search methodology entailed employing precise keywords and implementing pertinent filters to pinpoint articles that specifically tackle the incorporation of autonomous inspection technologies in the field of oilseed processing.

The literature search strategy for this thesis was carefully designed to include both modern technology and foundational techniques used in oilseed processing. Recent publications were primarily used to explore autonomous inspection technologies, which reflect the rapid advancements in this field. On the other hand, the examination of oilseed processing has also depended on traditional literature and books, since the basic principles and techniques in this field have largely remained the same throughout time. This approach guarantees a thorough comprehension of both contemporary technological incorporations and the constant procedures that define the oilseed industry.

To gain a more detailed understanding of oilseed processing and the incorporation of autonomous inspection technologies, a more detailed keyword strategy was utilized. The initial searches encompassed keywords such as "oilseed processing AND autonomous inspection technologies," "Seed storage AND oilseed processing," "oil extraction methods," and "vegetable oil refining." The selection of these keywords was based on their ability to address the specific aspects of each sub-research question, thereby facilitating a comprehensive examination of both current processing techniques and the possibility of technologies.

The second sub-research question relates to the integration of autonomous inspection technologies into oilseed processing. The literature search specifically focused oil industry broadly as there is lack of literature with respect to oilseed industry. The search was narrowed down using the keywords "autonomous inspection technologies AND oil industry" and "Robots in oil industry" For partially examining the third sub-research question, "What are the assessment criteria for selecting suitable autonomous inspection technology(s) in the oilseed processing plant?" The main emphasis was on the selection frameworks that are relevant to technology assessment methods as the keywords were expanded to encompass "technology selection models AND methods," "Multi-Criteria Decision Making" and "Analytical Hierarchy Process AND technology assessment." Further examination of third research question was answered in a case study.

2.3.2 Case Study (Cargill)

According to Yin (Yin R. , 1994) a case study enables the inquiring of a ”phenomenon within its real-life context”. To answer the research questions related to implementation of autonomous inspection technology in the seed oil extraction plant setting, an extended case study will be performed with Cargill B.V to understand the general oilseed extraction processes. Case study is an appropriate methodology for the exploratory research design and the study will be backed by the relevant literature review and by structured and semi-structured interviews. Amongst the four case studies developed by (Yin R. , 1994), a single, embedded design study is chosen with multiple units of analyses within the organization setting. Embedded studies are relevant when there are multiple units of analyses. Though according to Yin (Yin R. , 1994), the case studies have low internal validity, the research will have high external validity and generalizability beyond the settings of Cargill.

In this case study with Cargill, multiple sections of their oil plant will be studied and interviewed to understand the fundamental processes with feasibility and applicability of the solution. Moreover, the interviews with employees of Global EMEA IT innovation team from Cargill’s Schiphol office were also significant as they come under the bracket of decision making for technology selection. In this case study, interviews used for data collection were executed in three different time frames of the thesis. First set of interviews were executed to understand the business case. The second set of preliminary interviews were conducted to get more information on variety of expertise needed for next session interviews. The last set of interviews partially answered the third research question which were specifically conducted for finding the relevant assessment criteria of the potential technologies.

2.3.3 Interviews

Interviewing is relevant data collection method specially for exploratory research (Sekaran, 2016). The study involved the combination of semi-structured interviews. For semi-structured interviews, the interviewees were asked open-ended questions to facilitate the exploration of technology integration within the oilseed industry context. This allowed them to deviate from the structured questions and provide more detailed information on specific themes (Fox, 2009). Following steps were used for executing interviews.

- An extensive interview guide (in appendix 1) was prepared, listing questions with respect to the designation and expertise of each participant. This guide played a crucial role in ensuring uniformity and during the interview process.

- Interviews were arranged considering the varied time zones of the participants. The flexibility enabled optimal engagement and convenience for all participants during the interviews.

- The interviews were carried out remotely using Microsoft Teams, utilizing its functionalities to enable seamless communication. Before engaging in the interviews, all participants were furnished with technical assistance and instructions to guarantee seamless connectivity.

- During each session, visual aids such as images and flowcharts were presented through Microsoft PowerPoint to enhance understanding and engagement. These visuals were intentionally created to be unambiguous and instructive, in accordance with the subjects of the discussion.

- Interview Execution: Every interview commenced with a formal introduction aimed at establishing the context and ensuring the participants' comfort. The predetermined questions were presented systematically, and further questions were devised to explore areas of interest in greater depth. Every session of interview ended with a memorandum of appreciation.

- With the consent of the participants, all sessions were recorded. Indeed, this was pivotal for precise transcription in subsequent stages. Protocols were implemented to guarantee the preservation of confidentiality and anonymity of the interview data.

2.3.4 Sampling

The sampling technique is essentially used to select the right elements from the research population (Sekaran, 2016). As there is scarcity of information based on the technology selection and oilseed industry, it is important to select a set of people holding expertise in these areas. This study utilizes a non-probability technique within the broader category of sampling techniques, which includes both probability and non-probability sampling. In particular, the purposive judgment sampling technique is opted as it is particularly fitting when the research demands subject matter experts or individuals with relevant experiences to the study (Sekaran, 2016). Other than judgement sampling, snowball sampling technique was utilised in the preliminary stages as executive level interviewees referred and directed to other future interviewees amongst their acquaintances who held specific expertise for answering research question (Naderifar, 2017).

2.3.5 Questionnaire Survey

Most of the research in this thesis adopts a qualitative approach; however, the incorporation of a questionnaire survey, which is fundamentally quantitative, characterizes it as a mixed-methods study. This method is particularly effective in addressing a part of the third research question, which aims to establish the criteria for technology selection assessment. The questionnaire, as a tool in this study, is consistent with Multi-Criteria Decision-Making (MCDM) methodologies. The Paired comparison scale is specifically used when the participants examine the preferences and select from two choices at a same time. Hence, a survey was proposed to rank preferences pairwise using a modified paired comparison scale (Sekaran, 2016). The objective of this modification is to simplify the process and reduce the level of complexity, thereby facilitating the provision of precise preferences by respondents. A detailed information on questionnaire guide is partially explained in chapter 5 findings and appendix.

2.4 Data Analysis

For analysing the qualitative data of interviews, thematic data analysis methodology is used. Thematic analysis is a systematic method for analysing qualitative data that consists of six essential steps. At first, researchers fully engage with the material, carefully summarizing transcriptions to concentrate on the relevant details. Then, they derive codes from the transcripts to capture fundamental meanings and categorize comparable codes within groups. By merging these codes, which are adjusted to ensure they precisely represent the data and address the study questions, broader themes are developed. The coding in the research is two phases, where in first phase open coding is conducted. As this is exploratory research, it is imperative to examine interviews without a predetermined category to find new patterns (Sekaran, 2016). In the next phase axial coding performed to group the initial codes under a theme (Sekaran, 2016). The work concludes by providing a comprehensive analysis of themes and codes, often shown using a code tree to illustrate the organization and connections within the data (Braun, 2008).

2.5 Research Quality

The judgement of research quality in case study is performed by carrying out four different tests which are explained below (Yin R. K., 2018).

1. Internal validity and 2. Generalizability: The case studies are based on the inferences of the research which particularly not observable (Yin R. K., 2018). The internal validity test is only applicable for explanatory research, which is not the case here as this research is exploratory in nature (Yin R. K., 2018). The external validity or generalizability which is applicable for this research will be analyzed in the conclusion chapter.

3. Construct validity: This test requires ensuring that the case study in this thesis precisely mirrors the real-world phenomena it intends to describe. Effective tactics were used to improve construct validity include incorporating multiple sources of evidence to offer diverse viewpoints on the phenomena, establishing a coherent sequence of evidence to allow others to validate the process of reaching conclusions, and engaging key informants to evaluate drafts of the case study report to guarantee the accuracy and comprehensiveness of the depiction and conclusions (Yin R. K., 2018)

4. Reliability: The reliability of the research also reflects the repeatability in the interpretation of research meaning if another investigator follows similar research procdure or techniques then he/she should get similar results (Yin R. K., 2018). This thesis follows development of a case study database which facilitates keeping track and structuring of all data gathered during the study, so strengthening the ability to repeat and validate the findings.

2.6 Conclusion of Project methodologies

Chapter 2 outlined the methodologies which direct the investigation of autonomous inspection technologies in the oilseed processing sector. The chapter starts by providing a review of the exploratory research design, emphasizing its appropriateness for investigating topic areas that have a scarcity of available information. This foundation advocates for the development of qualitative methodologies, such as case studies and interviews, which are crucial for enhancing the comprehension of the topic matter. After the research design, the project methodology is expressed using the double diamond model of design thinking. This model functions as the fundamental framework for the experimental stages, systematically tackling the complex obstacles of incorporating novel technologies into well-established industries. Every stage of the conceptual framework—Discover, Define, Develop, and Deliver—presents distinct goals and results, which influence the course and implementation of the study. The chapter then examines several techniques for collecting data methods and explains the approach for a comprehensive case study with Cargill B.V. It serves as a prime example of how theoretical knowledge is practically applied. In addition to enhancing the data, interviews provide direct insights from industry professionals and are deliberately employed to improve the technology selection process.

Finally, the chapter establishes the foundation for Chapter 3, which will explore the technical aspects of oilseed processing methods, autonomous inspection technologies, and the crucial multi-criteria analysis necessary for successful technology selection. This research methodology guarantees a thorough comprehension of the current condition and prospects of technological integration in the oilseed sector.

3. Background study

3.1 Oilseed processing and Inspection

Given the lack of literature that deals with inspection methodologies in oilseed processing, this thesis prioritizes a pragmatic methodology in identifying and exploring inspection procedures arising directly from the workflow of oilseed processing. By grounding the inspection methodologies within the specific context of oilseed processing, this analysis ensures that the processes identified are directly applicable and tailored to the industry's unique operational requirements. The approach shall ensure that inspection techniques are developed through true industry-based activity, thus delivering practical and achievable results which stakeholders can readily use in practice. The pragmatic approach will also help in the modification and upgrading of the procedures based on interim feedback and problems faced during oilseed processing to help it remain relevant and effective. The process being developed helps understanding how inspections relate to the entire oilseed production units, from receiving the seeds to ensuring the final product's quality. Going through the process workflow also helps identify issues in subsequent stages that may result from insufficient inspection.

A typical oil seed processing consists of four distinct phases; seed storage and cleaning; seed preparation; seed extraction; and refinery which is shown in figure 4.

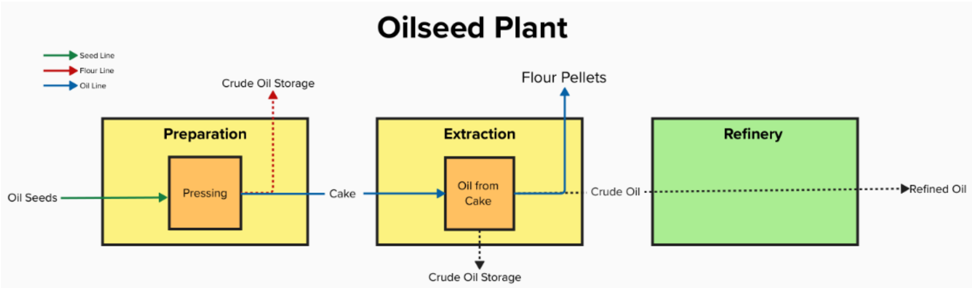

FIGURE 4. OILSEED PLANT OVERVIEW (AUTHOR'S OWN INTERPRETATION)

Seed Storage and cleaning

Seeds at the plant is reached by ship, train, or truck. Seed Shipments range in size from small lots to 60,000-tonne consignments. To ensure quality and weight control, every lot of seed received must be thoroughly analyzed to establish the seed lots' quality and weight. Incoming and outgoing truckloads allow for accurate measurements of seeds, for which discrepancy can easily affect the trader/seller's transaction. Weighing scales should, therefore be frequently checked and maintained because inaccuracy will readily affect the final product (Doosselaere, 2013). In the next step, sampling or stratifying is done to test all the major characteristics of the seeds before they go into storage; this includes moisture content, presence of undesirable substances, seed damage, and where there is oil production: protein and oil contents. To this effect, sampling equipment should be regularly checked for accuracy and integrity to maintain quality in seeds or seed integrity (Doosselaere, 2013).

Oilseed contain common impurities such as impurities from transportation, such as stalks, stones, weeds, and dust (Bockisch, 1998). On the one hand, cleaning seeds with the coarse screen is necessary to keep the quality of oil and the production efficiency. On the other hand, it is also to prevent the large impurities from entering the production machinery during subsequent processing steps and to avoid probable damage from stones or metals. Conveyor systems are used for seed transport. Therefore, provisions should be made for conveying systems within the plant on arrival that will accommodate considerable capacity, continuous product flow, be able to resist the degradation of product quality-all with a minimum of seed breakage. Internal sanitation and inspection should be easy and in zones liable to product buildup. Although the belt conveyors are usually designed for considerable distance material moves, chain conveyors and bucket elevators can be accepted as seal enhancements in applications and dust reduction (Doosselaere, 2013). However, almost all the belt conveyors used for the transport of the oilseeds require their repair frequently.

In the context of seed storage, generally oilseeds can be stored in concrete silos, steel silos or warehouses. There are few systems or processes which are required for the integrity of seed storage. For high-moisture seeds, it is important to install aeration systems for cooling and temperature control. The oilseeds can be exposed with fungi or insect infestation in the storage facility (Banga, 2019) (Tiwari, 2020). This infestation can deteriorate the seeds, externally and internally. Extracting data using conventional methods such as visual inspection, grain probes and insect traps, radiographic technique, NIR spectroscopy, X-ray imaging is labor-intensive, expensive, and inaccurate (Ho S.H, 2010). Hence, there is a necessity for a real-time monitoring sensing system to prevent this efficiently the collected data so obtained can be used for analysis for forecasting the condition of grain and to make decisions for the end-users to take precautionary measures, which can monitor the environment in which grain is stored, such as silos, bags, and metallic bins. To provide good quality agricultural products, it is mandatory to have an optimum temperature and humidity in either a storehouse, warehouse or silo when storing the oilseeds. Other than that, it is important to check the structural integrity of seed storage structure such as flat storages or silos.

Therefore, an autonomous control system will help to maintain the desired temperature valued for proper storing. For a proper storage it is important to control and monitor temperature variation and humidity (J., 2005).

Finally, the quality of the oilseeds, during unloading and storage significantly impacts the refining process. Seeds that are damaged in handling or improper inspection can lead to oil acidification, increasing the complexity and cost of subsequent refining stages like degumming or neutralizing (Doosselaere, 2013). Therefore, proper handling and storage conditions are important for the uprightness of oilseeds before they are transported for subsequent processes of oil extraction and refining.

Seed Preparation

After the seed storage, seeds are transferred to the common region or preparation building (Enrique Martínez-Force, 2015). The oilseed preparation includes steps of weighing, cleaning of seeds, cracking, conditioning, and flaking. Processes such as dehulling and drying can also be included depending upon the type of oilseed to be processed (Cravotto, 2023). The steps are prerequisite to oil extraction process.

Oilseeds are composed of small cells containing oil bodies, which are well-protected and tightly packed within the cellular structure. Effective oil extraction requires the preparation of seeds to break or weaken the cell walls for effective releasing of oil. This preparation also includes shaping the seeds to make it easier for solvents to flow through them during extraction. Additionally, mechanical pressing is carried out to extract oil before solvent extraction, mostly for seeds with top oil content, (Doosselaere, 2013).

Once the seed reaches plant, it is typically weighed before being sent through the cleaning process, which is similar to the steps followed in storage facilities (as mentioned earlier). The traditional process then moves on to cracking, where two or three high-speed, wavy corrugated rollers break the grain into smaller pieces. These rollers can be configured in various ways: horizontally aligned corrugated rollers, rollers rotating within a cylinder, or pairs of rollers with a cavitated surface instead of toothed. The machine's work capacity depends on its size and varies depending on the type of seed. Cracking mills that handle oleaginous materials can process about 1,000 tons per day of each type (Shahidi, 2005) (Cravotto, 2023).

Alternative technologies can also be used for seed crushing, often in combination with the dehulling process. In hammer mills, disk attrition mills, and other types of mills, a hopper feeds the seeds into the centre of vertical, corrugated disks. The particles are then propelled outward and collected. Another method involves pneumatic impact, where seeds are blown against a wall, causing them to fracture (Bockisch, 1998) (Shahidi, 2005). From here, the particles are thrown outwards, where they are collected. Another technique is based on pneumatic impact, where the seeds are blown against a wall, causing them to break (Bockisch, 1998). Upon reaching the processing facility, oilseeds undergo hot dehulling, also known as decortications, a method especially prevalent in seeds such as soyabean, which offers energy savings and reduces the production of fine particles relative to traditional cold grain systems. Common hot dehulling systems involve drying the grain to lower its moisture content to a suitable level for processing, dehulling while the seed remains hot, and directly transferring the conditioned cracks to flakers without cooling. This process not only conserves energy but also minimizes oil content which is residual (Shahidi, 2005).

The conditioning phase involves gentle heating of seeds between 60 and 75 °C in various types of equipment such as drum and stack conditioners, to enhance oil yield and prepare the seeds for further processing like flaking, which is critical for uniform cooking and efficient oil extraction (Shahidi, 2005). Flaking mills compress seeds between rollers to produce thin flakes, enhancing the solvent's access to oil cells. However, moisture released during flaking can impede solvent penetration, a challenge typically mitigated by air-drying the flakes. Expanders and extruders are employed to further prepare the seeds by heating under high pressure and then rapidly reducing pressure, which increases the matrix's bulk density and improves solvent percolation during extraction (Jablaoui, 2020). This process is vital for seeds with lower oil content, enhancing the quality and efficiency of the extracted oil and meal.

The processes, equipment involving seed preparation building need inspection. Weighing and cleaning equipment require routine maintenance and inspection to ensure that, besides quality seeds, accurate measurement products are also achieved. Periodical inspections on the machines, which include cracking mills, hammer mills, and disk attrition mills, would help operate effectively in service and prevent failure. Moreover, they check the integrity of the structure for the building that comprises the preparation facility to withstand all processing activities without any risk including leakages, corrosion, or cracks. It also comprises thermal imaging of all machines, like drum and stack conditioners, expanders, and extruders, as an integral part of the development of the optimum thermal parameters while processing seeds most effectively by the machinery, regarding proper functioning without any risk of disasters due to overheating or improper processing.

Seed Extraction using solvent extraction

There are typically two types of conventional oil extraction methods which are; mechanical pressing; and solvent extraction (with hexane). The solvent extraction process can extract <1% of residual oil from the oilseed. The extraction process is more efficient than mechanical extraction. Majority of the vegetable oil can be extracted from the process (Cravotto, 2023).

The most significant sub-processes in the solvent extraction process involve extraction itself, de-solventization of meal, drying of meal, cooling of meal, distillation of miscella, and solvent recovery. There is a high investment cost, especially for the establishment of a solvent extraction plant because the entire production building must be explosion-proof, and the daily processing capacity corresponds to 1,000–5,000 tons of seed, necessitating from USD 15-75 million in construction (Cravotto, 2023) (Hamm, 2012).

Hexane consists of a mixture of six hydrocarbon atoms. Hexane is the common solvent used worldwide in primary processing of oilseeds. It distils between 64–70°C and changes depending on the oil content of the mixture. Extremely strict precautions should be taken while these plants are under construction and during operation since mixtures of hexane vapors with air are explosive. Hexane and air mixtures are explosive within the range of 1.2% to 7.4% v/v hexane (Hamm, 2012). Low boiling point and high rates of recovery of oil achieved at relatively low costs of production make hexane the most preferred, though it is explosive and toxic (Hamm, 2012).

In the over-all process of solvent extraction, miscella breaks the cell walls to enter the oil bodies while it is present within the cells. Further diffusion, therefore, increases the pressure inside the cell, and the concentrated miscella diffuses outward from the cell. The above cycle repeats itself until equilibrium between miscella concentration in the oil material cells and the miscella bath is reached (Hamm, 2012). A vast number of factors significantly affect the efficiency of solvent extraction systems, including contact time, particle size, number of extraction stages, miscella flow rate, extractor temperature, and solvent retention. The precise control of these variables is very important in improving extraction efficiency and quality of the obtained product (Hamm, 2012).

The solvent extraction process involves several technical parameters for its efficiency and safety. Extraction time, contingent upon seed type, pretreatment, and equipment specifications, underscores importance of achieving an optimal contact time for maximal extraction efficiency. Within the residence time, characterized by wash and drain phases, lies a balance between effective extraction and solvent retention, a critical consideration in solvent-rich environments (Cravotto, 2023) (Hamm, 2012).

Important to solvent extraction is the solvent itself, hydrocarbon hexane, famed for its effectiveness in oil recovery but notorious for its propensity to explode when combined with air. Hence, it is significant to consider the design of facilities, guaranteeing adherence to safety regulations to minimize possible risks. The structural integrity of oilseeds is significantly affected by pretreatment methods, namely flaking, which reduces thickness and minimises the distance that the miscella must travel to reach oil bodies in the extractor. While crucial for improving extraction efficiency, these preparatory procedures require meticulous evaluation of particle thickness to achieve a balance between optimum extraction and operational expenses. Multi-stage counter-current extractors are increasingly favoured over single-stage extractors due to their improved solvent utilisation and heightened energy efficiency in solvent recovery. The calculation of the number of stages depends on the integration of wash zone time and the equilibrium stages that can be achieved within the planned timeframe. In extractor design, efficiency and cost-effectiveness converge to shape operational dynamics, highlighting the need for a nuanced approach (Hamm, 2012). Optimization of the miscella flow rate is crucial for achieving uniform extraction and minimizing solvent losses. Furthermore, the interaction between the temperature of the extractor and the diffusivity of miscella highlights the fragile balance between the effectiveness of extraction and the preservation of non-oil lipids and non-lipid constituents in the crude oil. The following drainage phase, after washing, is crucial in retaining the solvent, and the depth of the material bed significantly affects the time needed for ideal drainage (Cravotto, 2023).

Lastly, as extraction progresses to its last phase in de-solventization, the efficient removal of solvent becomes essential, underscoring the importance of optimizing drainage time to decrease the concentration of remaining residual solvent. After this process, extracted oil as crude oil is sent out to either oil storages or to the refinery. The oil storages keep the crude oil until the market distribution, otherwise crude oil is directly sent out the refinery building for further processing.

Different types of inspection processes are highly essential in the solvent extraction stage itself. Periodic maintenance of extraction equipment, along with checking the structural integrity of explosion-proof facilities and extraction building, is very important for safety reasons. The extractor temperature, the miscella flow rate, and the solvent retention value should be checked to ensure operational efficiency and safety. In addition, equipment checks during the desolventization process are needed to make sure that the best conditions prevail for the elimination of solvents and product quality. Considerations regarding heat need to be ensured for the condition of temperature, continuously controlled through the process.

1.4 Oil Refining

It is important to note that immediately the crude oil is extracted from oilseed extraction, it cannot be consumed. The oil must go through a very delicate and complex process of refinement to bring it up to expectation in safety and quality. This is so because crude oil contains a range of impurities that cannot only be limited to but comprise part of harmful substances like organic solvents, pesticides, among other impurities that substantially affect the whole stability and usability of the oil. The impurities range from wax, pigments, and oxidized fatty acids and really have a devastating effect on the quality of the oil if not removed. This is the major reason (Gharby, 2022) why most vegetable oils, including sunflower and rapeseed oils, require advanced refining after extraction to make them pure and of high quality for human consumption. Refined oil is completely odorless and tasteless; it also does not contain harmful contaminants. The latter two qualities make it excellent for use by human beings—one of the major applications in preparing food and its cooking (Gharby, 2022) Basically, there are two major methodologies the industry applies in the refining of vegetable oil 1) chemical refining, 2) physical refining. A detailed procedure in shown in figure 5.

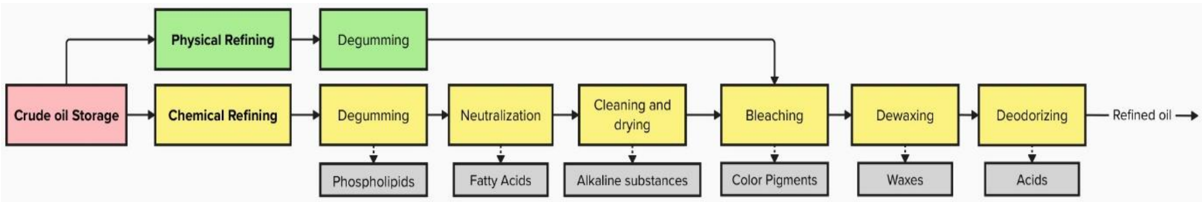

FIGURE 5. OIL REFINING STEPS

1.4.1 Chemical Refining

In the traditional process of refining, mainly free fatty acids are eliminated from the crude oil (Gharby, 2022). It has specific steps before the crude oil becomes refined oil.

1.4.1.1 Degumming

Degumming is a first step of vegetable oil refining, by which mainly phospholipids are removed along with small portions of carbohydrates, proteins, and trace metals (D. L. Lamas, 2016) (Goswami, 2013). These materials can bind metal ions like copper and iron and inhibit their catalytic activity, which may lead to free radical production in the oil (O. Zufarov, 2008). These compounds prevent storage and processing due to phospholipids combined with heavy metals which may enhance oxidation. Insufficient removal upon alkaline neutralization may lead to oil dark color upon storage (Patel, 2010). Accordingly, degumming should involve the removal of the unwanted components in a way that would reduce the problems of processing.

1.4.1.2 Neutralization

Oils with high levels of free fatty acids, hydrolyzed and oxidized vegetable oils, require refining. The most significant problem with free fatty acid is off-flavor and color formation that lowers the quality and stability of the oil (S.-C. Chew, 2016) (Ali, 2021). Either chemical neutralization by caustic soda or steam distillation in the case of physical refining can be used to remove free fatty acid (K. Essid, 2009) (Kochhar, 2001)

1.4.1.3 Washing and Drying.

After neutralization, it is further refined for the removal of residual alkaline materials like caustic soda and soap along with traces of metals and phospholipids. The degummed and to a huge extent decontaminated oil is then heated in a plate heat exchanger and emulsified with water in a centrifugal mixer. The latter undergo centrifugal separation and vacuum drying to a moisture content of less than 0.1% (Gharby, 2022). This results in oil of higher purity and better storage stability.

1.4.1.4 Bleaching

After washing and drying, the colored pigments of carotenoids and chlorophylls are left in oil and need to be reduced. The residual phosphatides, soap, lipid peroxidation products, and other contaminants dangerous for the appearance of oil and its stability are removed from oils (Rhazi, 2001), (Zschau, 2001). This step is rather important in respect of the final vegetable oils quality standards.

1.4.1.5 Dewaxing

Dewaxing is a process that removes natural waxes responsible for oil cloudiness, more so in oils while it's cold. First, bleached oil is heated to the temperature of 55°C to achieve liquefaction. After liquefaction, it is then slowly cooled to 10-15°C to form crystallization of wax. The filtered oil will have the crystallized waxes removed, leaving clear oil, and the wax is left as a by-product. This is an essential step for achieving the aesthetic qualities of the oil during winter (Gharby, 2022).

1.4.1.6 Deodorization

Deodorization is the final step of oil refining. It involves the removal of any residual free fatty acids and objectionable odors from the oil by applying a very high temperature between 180-240°C under a very high vacuum, usually between 2 and 8 mmHg. The process removes other volatile components like aldehydes, ketones, and alcohols and ensures neutrality of oil, making it fit for human consumption (Demirci, 2005) (S. T. Hussain Sherazi, 2016) (Narine, 2007).

1.4.2 Physical Refining

Physical refining of vegetable oils involves several key steps that are like those in chemical refining but exclude the alkali neutralization process. Instead of using caustic soda to remove free fatty acids, physical refining utilizes steam distillation, also known as steam refining (Gharby, 2022).

The physical refining process generally includes three main stages: 1) Degumming: This step involves removing phosphatides from the crude oil to prevent issues during the subsequent refining stages (Gharby, 2022). 2) Bleaching: After degumming, the oil undergoes bleaching to remove color pigments. It improves the visual quality of the oil. The process also includes filtration to ensure all pigments and impurities are completely removed (Gharby, 2022). After this stage, like chemical refining, dewaxing can be performed for specific seeds with high wax intensity such as sunflower and canola (Subramanian, 2006).

3) Deodorization: The final stage of physical refining is deodorization. It eliminates free fatty acids and other volatile compounds that can affect the taste and stability of the oil. By applying high temperatures and a vacuum, the process ensures the oil's neutrality and stability (Gharby, 2022).

As refining is the last stage of seed journey, it is significant to control and maintain the environment for delivering quality product. In other words, asset integrity assessments must be done regularly, paying attention to problems such as corrosion, leaks, and structural weaknesses likely to be faced by the main infrastructures, such as storage tanks, pipelines, or, for that matter, any other processing units. Apart from that, there are detailed equipment inspections, which include centrifuges, heat exchangers, vacuum dryers, and filtration systems so that each of these work at their best. This relates directly to the overall quality of the oil products that any refinery will produce. Attention is needed on several other process parameters comprising not just the critical ones like temperature and pressure, but also flow rates. Together with thorough inspection of environment and safety, this will ensure the refined process not only meets all the regulatory standards but also ensures the production of quality oil from uncontaminated sources in continuous manners.

3.2 Concept of Autonomy in Inspection technology

Autonomous inspection technologies can be categorized into three of such systems—automated, fully autonomous, and semi-autonomous (Norris, 2019). Each of these categories is distinguished by the level of human contact and decision-making autonomy, which are critical variables in the deployment and effectiveness of robotic systems in the oil industry. An overview of types is shown in Figure 6.

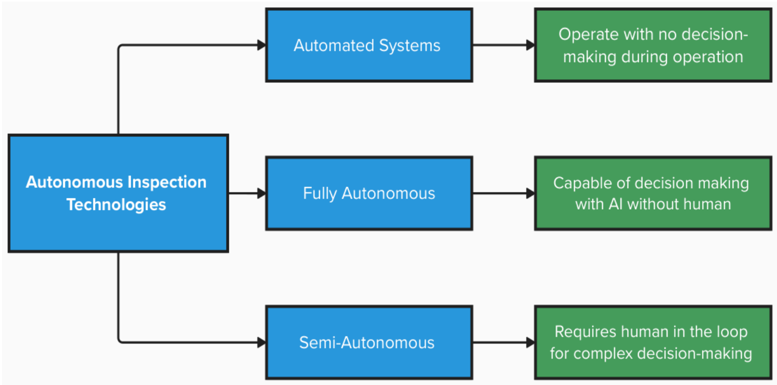

FIGURE 6. TYPES OF AUTONOMOUS INSPECTION TECHNOLOGIES

Automated systems

Automated systems are defined by their ability to function within strictly defined parameters, carrying out pre-programmed activities. These systems are made to carry out repetitive, well-defined tasks with minimal variation and little complexity in decision-making (Ding, 2016). When it comes to inspection technologies, examples of such systems would include pipeline inspection devices that process data based only on pre-established criteria, following a predetermined path and without modifying it in real time to discover leaks or anomalies.

Fully Autonomous Systems

The highest level of robotic independence is achieved by fully autonomous systems, which are intended to function without human direction or involvement. These systems can react intelligently to changing environmental stimuli because they are equipped with sophisticated sensors, data processing tools, and AI-driven algorithms (Lam, 2016). The distinguishing characteristic of these systems is their capacity to adjust to novel and unforeseen situations via acquired or developed tactics, akin to the ANYmal C robot's capability to maneuver and oversee assignments in intricate landscapes and dangerous surroundings commonly found in the oil and gas industry. These kinds of technologies are essential in situations where it is hazardous or unfeasible for humans to operate (Norris, 2019).

Semi-Autonomous Systems

Semi-autonomous systems strike a balance between automated and fully autonomous technologies, incorporating elements of both to improve flexibility and safety. These systems need human supervision while making decisions, especially when faced with intricate, erratic, or unusual situations that are outside the current scope of artificial intelligence (Norris, 2019). Human operators may step in to change parameters, override a decision, or assist the system during a crucial portion of the operation. Many Drones for instance, may navigate around barriers on their own, but sometimes human intervention is needed to evaluate structural problems or to determine the severity of flaws that have been found.

The present thesis uses a broad definition of "autonomous" to refer to a variety of technologies with differing levels of autonomy from human operators. Although all these technologies are frequently referred to as "autonomous," it is crucial to understand that this term encompasses automated, fully autonomous, and semi-autonomous systems. These categories stand for varying degrees of machine autonomy and human interaction. The term "autonomous" is used broadly in this thesis to describe systems that may perform tasks independently under specific conditions or that may require human input for decision-making in complex scenarios. It does not, however, imply total independence from human intervention. It is essential to have this advanced knowledge of autonomy to properly discuss the implementation and consequences of these technologies in the oil industry.

3.3 Autonomous Inspection Technologies in Oil Industry

In the oilseed industry, which includes operations from farming to refining, there is considerable opportunity to improve safety and efficiency by automating manual inspection procedures. By formulating comparisons with autonomous inspection technologies used in different industries, the oilseed sector can obtain significant advantages. The implementation of such technologies has the potential to decrease human exposure to hazardous conditions and optimize inspection procedures, which are essential for upholding the stringent standards necessary in oilseed processing. This integration not only corresponds to the intricate operational requirements of the sector but also guarantees significant enhancements in overall economic efficiency and safety protocols. This analysis of technological applications in the oilseed industry establishes a fundamental framework for investigating the classification and complete evaluation of these novel solutions in this section. Based on type, the market of inspection robots in onshore oil industry are categorized into two categories: Unmanned Ground Vehicles (UGV), and Unmanned aerial vehicles (UAVs) (Leijian Yu, 2019).

Unmanned Ground Vehicles (UGV)

Unmanned Ground Vehicles (UGVs) have been around since the 1960s, with one of the earliest significant developments being "Shakey," a pioneering mobile robot created in the late 1960s. Shakey was designed as a testbed for artificial intelligence research at the Stanford Research Institute, marking a key milestone in the evolution of robotics (Nilsson, 1984).

Vertical Structure Inspection

This has spawned a great deal of interest in wall climbing robots designed for the purpose of inspecting vertical structures, which can be differentiated based on the technology employed for the climb. One of the main issues at the design and development stage of such a robot is reliably adhering to a variety of walls or surfaces without significantly impeding the movement of the robot. Climbing mechanisms can be generally divided into three categories based on principles of adhesion and locomotion: magnetic adhesion mechanisms, pneumatic adhesion mechanisms, and bio-inspired grasping grippers. Since the structures in the oil and gas verticals are predominantly made from carbon steel, the inspections pertaining to these structures can be done with a great advantage using magnetic adhesion mechanisms. Several schemes have been developed based on magnetic adhesion. Probably the most frequently used permanent magnets are applied as an adhesion mechanism for sticking to the walls. This method offers the important advantage of not requiring extra power for the adhesion mechanism, which increases the energy efficiency of the robot. However, when variable adhesion is needed in certain scenarios and it becomes necessary to switch between states of adhesion quickly, the electromagnetic adhesion mechanisms become quite useful, as developed in (M. F. Silva, 2012). Pneumatic adhesion mechanisms are another technology that has been hugely utilized in the robots designed for inspecting vertical structures. In this method, adhesion force is proportional to the pressure difference between a pressure chamber or suction cups and the surrounding atmosphere. In contrast to magnetic adhesion, which can work only on ferromagnetic surfaces, pneumatic adhesion is versatile and can attach to a much broader range of materials. Suction cups are one of the popular choices in this category consisting three suction cups, one supporting plate, one vacuum pump, and some accessories has been designed. The ICM Rover also applies a vacuum adhesion mechanism as a fall-protection system during inspection missions. Biomimetic adhesion methods are also being applied to state-of-the-art climbing robots (Leijian Yu, 2019).

Pipeline Inspection

Locomotion style is, therefore, a critical consideration for onshore pipeline inspection robots, as they have strong influences on the overall performance of such robots. Based on the driving source and control capability of the motion mechanism, these can be categorized into many types: pig shaped, screw, tracked, inchworm, legged snake, and wheeled types. It is a simple, pig-shaped device that accumulates data from the interior of a pipeline (A. A. Mazreah, 2017). It flows with the flow of oil or gas in pipelines to perform its inspection tasks. Most importantly, it has no independent drive and therefore depends on pressure from the flowing oil or gas to propel it through the pipeline. The wheeled robots (Ma, 2018) make use of wheels that are in constant contact with the pipe wall. Such robots can easily adapt with various pipeline conditions because it makes use of springs that assist in the consistent contact. Tracking robots are often mentioned as alternatives to the wheeled robots, and these can prove to be options to the former (Yi, 2012). Many wheels are connected to a belt in this design, increasing the contact area to the pipe wall and minimizing the possibilities of losing contact, especially in an uneven surface. Legged Robots have multiple legs interfacing the pipe wall that enable them to carry out highly complex maneuvers (Ohol, 2017). This type is very apt for traversing pipelines with obstacles or irregularities (Leijian Yu, 2019). The inchworm type creates traction by applying large forces either at the front or at the back module; this feature makes it effective in curved pipe inspections (C. Nițu, 2019). Snake robots are made up of several identical segments connected by joints that can make a variety of motions; their flexibility also makes them applicable to complex geometries of pipelines (F. Trebuňa, 2016). Finally, screw-type robots progress by means of a rotary motion, and they are therefore very useful in vertical pipelines where they can produce reliable and constant movement (H. Tourajizadeh, 2018) (Leijian Yu, 2019).

Unmanned aerial vehicles (UAVs)

UASs are the digital transformation force in the O&G industry and manifest new problem-solving methods for activities that have traditionally been associated with inspection, monitoring, and surveillance (Leijian Yu, 2019). Such sophisticated systems are increasingly being adopted because they bring dramatic improvements in operational efficiency, safety, and data precision in scenarios that are hazardous, difficult, or financially costly for humans to access. UAS technology enables real-time infrastructure, pipeline, and other environmental conditions that are key to reducing downtime, minimizing risk, and improving productivity in the industry. This shift toward the digital, illustrated by several studies reflects the importance of UAS in the modernization process for the OandG sector and charts a course for more resilient and responsive operations (T. R. Wanasinghe, 2020) (Smith, 2015) (AlNoaimi, 2019) (Wesley, 2019) (Saadawi, 2019) (Marathe, 2019).

Basically, a UAS is an aerial platform vehicle that may be remotely piloted or autonomously self-controlled; it often carries specialized payloads to fulfill specific mission objectives related to inspection. The remotely controlled UAS has the piloting done on the ground for managing the flight remotely, while the on-board autopilot system accomplishes this for the autonomous UAS. Sometimes, a hybrid approach is followed wherein the takeoff and landing are done by the pilot in command from a remote location while the autopilot undertakes the rest of the mission. In fact, regarding the oil and gas industry, sensors are generally utilized as payloads on UAS, which are controlled either remotely or through semi-autonomous methods to execute its tasks. UAVs equipped with sensors can offer another choice to traditional inspection methods, saving both time and cost. A survey conducted by the North Sea E and P company revealed that using UAVs for asset inspections can be faster and cost half as much as traditional methods (M. A. Ma'sum, 2013). Currently, all commercial inspection UAVs are manually operated. During the inspection, an experienced pilot controls the UAV, while another experienced inspection engineer monitors the live video feed (T. R. Wanasinghe, 2020).

Inspections have been brought under through Cyberhawk from global leaders like BP and Shell in UAV based inspections. The Intel Falcon 8+ as adopted by Cyberhawk shown in figure 9**.** has been proven as being dependable and to operate effectively (Intel and Cyberhawk Inspect Gas Terminal through Lens of Commercial Drone Technology - Cyberhawk", 2019) (T. R. Wanasinghe, 2020). It has V-shaped patented design having eight rotors for stability and free data capture. It carries three redundant IMUs and data fusion technology, hence guarantees safe and responsive flying. For inspection purposes, it is rigged with a RGB and thermal camera for easy navigation and the capability to collect detailed data for orthography and 3D construction, which have become one of the indispensable tasks during asset inspection and post-analysis (I. System, "Intel® Falcon™ 8+ System, 2019) . Another developed inspection UAV is the ELIOS by Flyability, which represents the very first collision-tolerant drone as shown in figure 8. It has a carbon fiber shell to ensure collisions take place. The device bounces off obstacles and rolls over surfaces to locate its way. With High Definition and thermal camera, and LED system, the UAV can perform an inspection within any lighting conditions. Currently, two qualified human engineers are needed to inspect with just one UAV. These tasks, if independently conducted, would increase the pace of inspection, bring about cost efficiency through a reduction in labor costs, and avoid accidents due to human failure (T. R. Wanasinghe, 2020).

FIGURE 8. ELIOS 3 BY FLYABILITY

FIGURE 7 INTEL FALCON 8 PLUS BY CYBERHAWK

Advantages of UAVs in the Oil Industry

There are enormous benefits of UAVs in the oil and gas sector, regarding enhancing efficiency and safety and improving cost-effectiveness under different operating environments. One important benefit is that these drones have an ability to conduct asset integrity inspections on their own, hence no need for human presence in hazardous environments. UAVs reach almost inaccessible places, such as offshore platforms, flare stacks, and confined spaces, for which using scaffolding or rope access as the conventional method comes with extremely high risk and is extremely time-consuming. It can allow various sensors and cameras, which helps to provide good-quality, real-time data for more accurate monitoring and decision-making. Besides, UAVs save a lot of the time and costs associated with such inspections. For instance, the use of drones in place of scaffolding can reduce inspection costs and time by as much as 75%, with dramatic impacts on the overall downtime of critical infrastructure. Their fast speed in covering large areas makes a strong case for pipeline inspection, environment monitoring, and geophysical surveys to raise the operational efficiency in the oil and gas sector (T. R. Wanasinghe, 2020).

Challenges of incorporating UAVs in the Oil Industry

Despite having many advantages, there are several challenges to deploying the technology in the oil and gas sector. Most probably, the greatest technological limitation of UAVs is their endurance and load capacity. Very low endurance represents a constraint by batteries on most UAVs and can really become quite a nuisance in the case of large operations. Moreover, extreme temperatures, high winds, and corrosive atmospheres that are usual in any oil and gas operation can have huge effects on the reliability and lifetime. Besides, the regulations vary greatly between the regions, as sensitivity, population concentration, or environmental need may change. For example, high population or environmental sensitivity in regulation would constrain a UAV flight path hence affecting its range of operation. Also, more experienced operators and data analysts will be required to deal with UAVs, who might need more training. Issues of cybersecurity also come in the limelight since UAVs are more prone to being hacked and their data exposed, risking sensitive information. Generally, these are challenges that must be surmounted to realize the full potential that UAVs will hold for the oil and gas industry (T. R. Wanasinghe, 2020).

Advantages of UGVs in the Oil Industry

Unmanned Ground Vehicles have a host of advantages in use in operational scenarios that are very divergent. The functioning agility makes it very useful in confined environments. It is quite capable of moving along narrow corridors and handling jobs involving physical contact, such as turning valves or picking up tools. Their operational carrying capacity for heavy payloads and different sensors makes them very effective in inspection applications that can cover comprehensive, lengthy areas, with the ability to conduct detailed analyses over long periods. The operational durations for UGVs are generally much longer compared to a UAV, which is important when the task requires sustained activity. Furthermore, UGVs are built to travel on different kinds of surfaces, whether slippery or uneven, with their crawler belts or robust wheels that make the performance stable in challenging environments (Miura, 2018).

Challenges of incorporating UGVs in the Oil Industry

On the other hand, there are also some limitations to UGVs that pose a problem in their application in practice. One of them is the limited reach; it has lowered functionality in high-rise applications and many times needs extra mechanisms for completion or with the cooperation of UAVs to execute the best results. The slower speed, relatively, can be a disadvantage in scenarios where rapid response is required. Additionally, while UGVs are competent in small or confined spaces, they are limited in very tight or vertical environments in which UAVs could have a decided advantage due to their ability to move around and over obstacles more freely. These limitations underline the need for selecting the right type of unmanned vehicle for a specific mission requirement (Miura, 2018).

3.4 Techniques for Technology Selection

3.4.1 Technology selection

The literature on technology management elucidates the complex stages involved in managing technology inside organisations, encompassing technology identification to protection (Gregory M. J., 1995). Each stage has a specific objective and needs careful consideration to guarantee the best possible use of technology and reduction of risks. More precisely, technology identification refers to the process of investigating different technological options that are currently accessible in the market. Conversely, technology selection entails crucial decision-making procedures to ascertain the most appropriate choices according to organizational requirements.

Technology selection involves not only choosing the most technologically sophisticated alternative but also incorporating strategic decision-making (Ragavan, 2003). This entails assessing technologies considering both objective and subjective criteria. Objective criteria encompass components such as cost, technical specifications, and implementation time, while subjective criteria include the usability and user interface of the technology, which are often overlooked in the decision-making process. The decision making in a choice of the technology is needs some sort of data assembly of all the alternatives and assessing them each other based on some criteria or sub criteria (Gregory M. L., 1997). It is important to assess technology systematically as it can lead to process failure if not managed and assessed well (Huang and Mak). To address it as a multi-criteria decision-making problem as described in a literature (Triantaphyllou, 1998), it is necessary to adopt a holistic approach in technology selection that values both the tangible and intangible aspects of technology.

3.4.2 Multi Criteria Analysis Methods

For decision-making support in oil industry in general, Multi-Criteria Decision-Making (MCDM) is one of the most popular and widely used essential computational methods to handle intricate decision situations when there is no perfect solution (Mahmood Shafiee, 2019). Instead, a compromise solution that most closely matches the preferences of the decision-maker is sought (Justyna Kozłowska).

Another prominent method in MCDM is Simple Additive Weighting (SAW), renowned for its straightforwardness and intuitive approach in representing preferences through an additive linear function (Tzeng, 2011). Both VIKOR and TOPSIS approaches employ an aggregating function to quantify the proximity to an ideal solution. VIKOR aims to identify the nearest alternative to this ideal, while TOPSIS evaluates alternatives based on their proximity to an ideal solution and distance from a negative-ideal solution (Opricovic, 2004). The ELECTRE methods depend on pairwise comparisons, employing concordance and discordance indices in conjunction with threshold values to assess multiple options (Effatpanah, 2022). PROMETHEE, a comparable approach within this classification, is founded on the concepts of dominance relationships and extends the idea of decision-making criteria (Mareschal, 1984). The significance of employing methodologies in robot selection becomes evident within the framework of autonomous inspection technology. A model utilizing Data Envelopment Analysis (DEA) to select technology was proposed, with robot selection serving as a numerical illustration to showcase the practicality of the approach (Khouja, 1995).

Another MCDM technique is the Analytic Hierarchy Process (AHP), which was created by Saaty in 1980 and subsequently improved in 2005. The Analytic Hierarchy Process (AHP) is particularly efficient in breaking down intricate decisions into more manageable and organized elements, so enabling a precise evaluation of various alternatives (Saaty T. L., The analytic hierarchy process (AHP), 1980). At the outset, the decision problem is structured into a hierarchical model including the primary objective, influencing factors, and possible alternatives, which enables a methodical assessment. The procedure continues by conducting pairwise comparisons to evaluate the relative significance of each parameter, so generating a judgment matrix that measures these evaluations. Subsequently, weights are computed based on the judgment matrix, and the coherence of the comparisons is assessed to guarantee logical and statistical validity. The final step involves combining these weights to ascertain which options most closely correspond to the overarching objective, accounting for the relative significance of each criterion (Saaty R. , 1987)

The versatility of the AHP was demonstrated through its integration with a Group Decision Support System (GDSS) for the purpose of selecting Advanced Manufacturing Technologies (Mohanty, 1998). The integration of AHP underlines its ability to enable collaborative decision-making, strengthen stakeholder agreement, and promote strategic alignment within organisations, so establishing it as an essential instrument for efficient technology selection.

3.5 Conclusion of Background Study

Chapter 3 offers an in-depth analysis of oilseed processing, inspection techniques, and the impact of autonomous inspection technologies on improving operational efficiency and safety. The workflow of oilseed processing encompasses seed storage, preparation, extraction, and refining, highlighting the necessity of inspection at each stage to uphold quality and avert expensive complications, including equipment damage and oil acidification. Autonomous technologies, such as Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs), serve as essential instruments for improving inspection processes within the oilseed industry. These technologies provide benefits, including decreased human exposure to hazardous environments and improved inspection accuracy; however, they encounter challenges such as restricted endurance and operational range.

This chapter examines the selection of suitable technologies for inspections, employing MCA and MCDM techniques to balance objective and subjective criteria in the decision-making process. Methods such as the AHP are recognized for their efficacy in managing complex decision-making and assessing multiple technological alternatives.

The background study concludes by establishing the foundations for the resulting phase of analysis and design. Chapter 4 will analyse the findings from this background study, establishing a foundation for the development of an inspection methodology. This chapter will focus on the second diamond, which signifies the "develop" phase in the double-diamond framework, transitioning from exploration to solution development.

4. Systematic Assessment Approach

4.1 Background Study Analysis and design requirements foundation

The significance of a meticulous and systematically defined strategy in the implementation of autonomous inspection technologies in the oilseed sector cannot be pointed out enough. The literature review presents a convincing explanation that emphasizes the need of recognizing specific areas within the oilseed process, determining particular use cases for inspection, using multi-criteria decision-making approaches, and establishing strong evaluation criteria for technology selection. Each of these factors carries a crucial function in guaranteeing that the incorporation of new technologies is both strategic and advantageous. In this analysis, we explore the arguments for each component in greater detail, relying on the data obtained from the literature review as it will work as a foundation for design requirements.

4.1.1 Scoping the Area in Oilseed Processing

The oilseed processing operation comprises a sequence of intricate and interconnected phases, each presenting its own distinct difficulties and complexities. Each stage of the process, from seed storage and cleaning to oil extraction and refining, exhibits unique conditions and possible risk factors that could be enhanced using autonomous inspection technologies. An analysis of the literature reveals the wide range of these stages and the distinct operational requirements they generate. Establishing the scope of these processes is essential as it enables the identification of the specific areas where technological interventions can be most advantageous and essential. Targeted technological solutions have the potential to change crucial areas such as real-time monitoring in seed storage to combat spoilage and precision in the extraction phase to optimize oil yield (Shahidi, 2005). In the absence of a clearly defined scope, it would be difficult to optimize resource allocation or determine the most influential areas for technology implementation.

4.1.2 Identification of Inspection Use Cases

Equally important is the identification of specific use cases for inspection within the determined scoped areas. The literature review provides an in-depth review of the operational challenges experienced by the oilseed industry. These challenges include the management of seed integrity during storage, the preservation of extraction process efficiency, and the maintenance of oil purity during refining. Each of these areas may derive advantages from distinct inspection technologies, such as visual inspections for seed quality, sensors for storage conditions, or robotic inspection for inaccessible areas in processing infrastructure. To develop a planning method for deploying autonomous technologies, one of the steps involve identifying potential use cases within an industry setting (Hendrik Unger, 2018). The identification of these use cases enables stakeholders to gain a deeper understanding of the practical implementations of autonomous technologies, customize solutions to address requirements, and improve overall operational efficiency and product quality.

4.1.3 The Necessity of Multi-Criteria Decision-Making

Determining suitable technologies for the oilseed industry is a complex undertaking that requires considering many aspects including cost, efficiency, integration ease, and potential return on investment. A literature review confirms that Multi-Criteria Decision Making (MCDM) is an effective method for navigating this complexity. MCDM approaches such as AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) offer a systematic framework for assessing technologies based on several criteria concurrently. This methodology is crucial for making well-informed decisions that consider both the numerical and qualitative considerations of each technology, so assuring that the chosen solutions are in line with the strategic objectives and operational needs of the industry.

4.1.4 Need for Assessment Criteria

The development of strong evaluation criteria is essential for the efficient selection of technologies. The criteria must be sufficiently thorough to encompass all facets of the technology's performance and its incorporation into current systems. The literature review indicates that these criteria may encompass technical specifications, compatibility with current infrastructure, effect on safety and quality, and compliance with industry regulatory requirements. The criteria must also align with the priorities and values of the stakeholders, guaranteeing that the technologies not only enhance efficiency but also optimise safety, minimise expenses, or accomplish other strategic goals. Careful and precise definition of these criteria is essential to impartially evaluate the potential of each technology and prevent any prejudiced or inadequate assessments.

In conclusion, the background study provides strong evidence for the necessity of a well systematic approach to incorporate autonomous inspection technologies in the oilseed industry. By delineating the operational domains, pinpointing particular use cases, utilizing MCDM approaches, and establishing rigorous selection criteria, the industry can guarantee that the implementation of new technologies is both strategic and advantageous.

4.2 Designing systematic approach

Oilseed processing from storage to extraction is a complex set of processes; hence, its integration with technology should be both systematic and scientifically justifiable. The foundation in building an effective strategy for the integration of relevant academic papers related to the approaches for technology selection are given here so that the adopted methods give theoretical strength along with pragmatic viability while selecting this industry's operational challenges.

The autonomous inspection technologies for the oilseed industry need implementation in a systematic manner because the involved processes, from seed warehousing to oil production and purification, inherently carry a lot of complexities. Therefore, the primary step in this multifaceted approach is the clear definition of the technological problems, which forms a base for all subsequent decision-making processes. Drawing from a thorough analysis of the existing literature, which further highlights the need for clear outlining of operational phases and awareness of specific technological solutions, it is therefore of importance to ensure that the said technological interventions correspond to the real needs of the industry. This is even more supported by the methodologies presented in the two studies (Farshidi, 2018) (Yung-Chi Shen, 2010). The first study, points out the imperatives of problem definition and feature selection thoroughly and in a systematic manner in decision-making processes regarding software (Farshidi, 2018), while the other study proposes hybrid fuzzy Delphi method with AHP for prioritizing and enhancing these criteria through expert consensus (Yung-Chi Shen, 2010). Though problem definition has its significance, it must not be a considered as one of the most critical requirements because, technology selection can also rise due to sheer optimism of technology implementation. Since the broad operational details are highlighted within the literature review, specific and targeted technological solutions tend to become very necessary to improve efficiency and productivity at various levels of the oilseed processing, thus, an exhaustive scoping phase as well use cases for targeting solutions become significant.

As it a multi-criteria problem it is important to identify relevant assessment criteria for evaluating the technologies. The step-by-step approach used in both the studies stresses on having an accurate selection criterion as a necessary foundation for using multi-criteria analysis (Farshidi, 2018) (Yung-Chi Shen, 2010). Therefore, it is important a have a decision-making framework. From the study where a hybrid model is proposed for emerging technology selection, in which both AHP and Delphi methods are used as decision making frameworks, it is important to note that only AHP can also be opted as it is proven method for technology selection. While the Delphi method has been proven with the hybrid model, it is yet not considered for the timeline constraints of this research project. Other than that, the method is quite demanding for researchers and participants, which often leads to participants dropping out may include the extensive time commitment required, loss of interest during intervals between round (Donohoe H. M, 2009).

Following the establishment of a problem definition and assessment criteria selection, the identification and evaluation of technological alternatives take precedence. These steps are found to be critical in the research done by as detailed in both research papers specifically on AHP for technology selection with its steps (Akkineni V. Sivarama Prasad, 1990) (Goh, 1997). For employing the framework, there are four distinct steps; 1) Hierarchical structuring of decision criteria with technology alternatives, 2) Pairwise comparisons to assess the relative importance of each criterion, 3) Calculation of priority weights and a consistency check to ensure reliable judgments, and 4) Synthesis of outcomes to aggregate the weights and produce a final ranking of alternatives. This process ensures a thorough and systematic evaluation aligned with strategic objectives.

It is methods of this nature that ensure that a comparative study is carried out systematically with pairwise comparison and weight assignment so that each technology in view is weighed against a carefully developed set of criteria representatives of operational needs and strategic objectives of industry. AHP thus offers the balance between the pair of comparison data of qualitative and quantitative factors and expert inputs and is reliable in the process of evaluation (Goh, 1997). The final list, ranked by technology, which results from this process, provides an informed and strategically aligned choice (Yung-Chi Shen, 2010). The ranked technology must be optimal (Ragavan, 2003) as selecting incorrect technology can lead to process failure (Huang and Mak). The already validated systematic multicriteria decision-making process then gets culminated in a robust technology selection framework.

Process Elements

On the top of steps for ranking technologies, it is also significant to consider process elements as well into the approach. This study proposes a structured way for selecting autonomous inspection technologies within the oilseed industry, addressing significant gaps in the literature related to systematic processes and stakeholder involvement in technology decision-making. For understanding the significance of processes and embedding it into the step-by-step approach, a research paper was studied, where a framework was created to select advanced manufacturing technologies similar to autonomous technologies like a robot in the industry (Mohanty, 1998). The study also emphasizes importance of engaging various management levels in the decision-making process due to the complex interplay of internal and external factors affecting technology selection.

The model proposed by Mohanty includes a systematic process that involves defining the technology selection problem, identifying potential solutions, and evaluating these based on set of criteria that go beyond mere financial metrics. model is particularly relevant for the oilseed industry, where decisions on technology adoption need to factor in operational efficiencies, safety, and cost, ensuring that the chosen technology aligns with broader organizational strategies. Stakeholder involvement is another critical element emphasized in the model, recommending the use of participatory approaches such as the Analytic Hierarchy Process (AHP) for criteria evaluation. This approach ensures that the selection process is inclusive, drawing on the diverse insights and expertise of stakeholders across different levels of the organization. In the context of the oilseed industry, this means involving plant directors, engineers, and operational managers to collaboratively define selection criteria and assess technology alternatives (Mohanty, 1998).

The framework also highlights the integration of tacit knowledge (from individual experiences and expertise) and explicit knowledge (documented and easily shared). For the oilseed industry, leveraging both types of knowledge can facilitate a better understanding of the specific technological needs and the potential impact of new technologies on existing processes. This aspect is crucial for industries like oilseed processing where technological and market conditions evolve quickly, necessitating a flexible approach to technology evaluation and implementation (Mohanty, 1998).

In practice, this framework particularly in the context of process elements can be modified and adapted implemented in this by first establishing a clear set of strategic objectives for technology adoption, which could include enhancing product quality, reducing waste, or improving operational efficiency. A multidisciplinary team would then be formed to oversee the technology selection process, conducting detailed market research, and utilizing tools like AHP to weigh the various technological alternatives against the defined strategic objectives. The involvement of diverse stakeholders not only enriches the decision-making process but also aids in the smooth implementation and acceptance of new technologies.

The interplay between defined industry needs, expert assessments, and methodological rigor leads to the set of design requirements for the systematic approach in context of oilseed processing.

4.3 MosCoW Prioritization method for design requirements

The research uses the *MoSCoW approach (in figure 9.)* to give priority to the design requirements to establish a well-defined and organized framework for decision-making. The MoSCoW prioritization method is broadly applicable, suitable not just for general requirements and tasks but also for acceptance criteria, tests, and other related elements and activities (Moran, 2015). Its flexibility makes it an ideal choice for prioritizing design requirements, allowing for a clear focus on essential features first and permitting the integration of less critical aspects as resources permit. The methodology seeks to precisely define the problem, assess the potential for technology, and evaluate technological alternatives, so assuring that the decisions made are well-informed, efficient, and in line with industry requirements. Sources leading explicitly to the design requirements for step-by-step approach have been given a reference after each statement of requirement (REQ). All other requirements are implicitly proposed by the researcher based on literature and own interpretation.

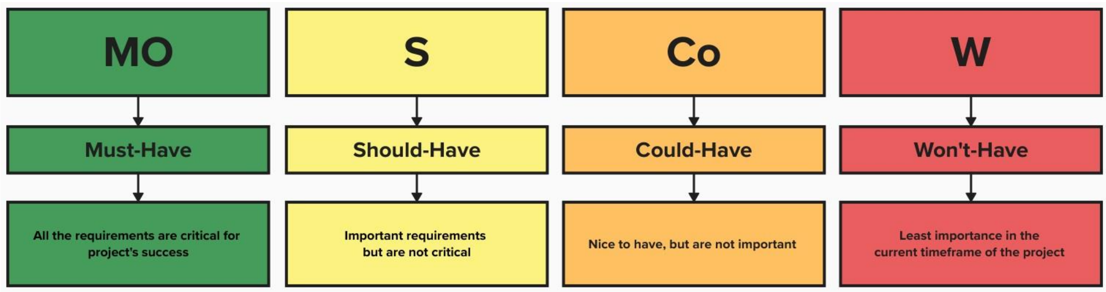

FIGURE 9. MOSCOW APPROACH (AUTHOR'S OWN INTERPRETATION)

Must Have (Mo)

1.1 The approach must be able to rank the technologies to identify the most optimal technology alternative.
(Yung-Chi Shen, 2010) (Huang and Mak) (Ragavan, 2003).

1.2 The approach must analyse and identify which stages of oilseed processing (from storage to refining) could provide a targeted technological solution(s). (Shahidi, 2005) (Yung-Chi Shen, 2010)

1.3 The approach must Identify and document all the potential use-cases which are required for deploying autonomous technologies within the oilseed industry to ensure comprehensive coverage. (Hendrik Unger, 2018)

1.4 Multi-Criteria Decision-making Framework:
a) Establish an approach for assessing technology options, where subjective judgements from experts can be quantified.
b) An approach must incorporate all major steps for the multi-criteria Analytical Hierarchy Process for structured decision-making. (Yung-Chi Shen, 2010) (Farshidi, 2018) (Akkineni V. Sivarama Prasad, 1990) (Goh, 1997)

1.5 The approach must find all the relevant assessment criteria for the selection of autonomous inspection technology. (Yung-Chi Shen, 2010). (Farshidi, 2018) (Akkineni V. Sivarama Prasad, 1990) (Goh, 1997) (Gregory M. L., 1997)

1.6 Technology alternatives: A step where technologies compatible within oilseed industry are identified and listed. (Akkineni V. Sivarama Prasad, 1990) (Goh, 1997)

1.7 Stakeholder involvement and Feedback Mechanism: Implement a structured approach for collecting and integrating feedback from industry experts, operators, and strategic decision-makers to enhance the technology selection process continuously (Mohanty, 1998)

Should Have (S)

2.1 The approach should have a reasoning on which it provides a clear definition of problems related to manual inspection methods. (Farshidi, 2018)

2.2 The approach should compile a list of viable technologies with a wide category of technology alternatives and filter out based on expert judgements (Yung-Chi Shen, 2010)

2.3 A step establishing main criteria arising from wide sub-criteria that evaluate the technology from holistic perspective. (Yung-Chi Shen, 2010)

Could Have (Co)

3.1 Supplementary evaluation methods: A step for cost-benefit analysis, risk assessment, and life cycle assessment for testing feasibility and sustainability of each technology.

Will Not Have (W)

4.1 Market analysis during the initial phases: During the initial phases, prioritize the assessment of the technical and operational suitability of technologies, rather than engaging in extensive market trend analysis and detailed economic forecasts.

4.2 Use-case priority: A step where inspection use-cases are ranked, prioritized, and categorized for business objectives.

4.3 Technology Pilot Data Integration: A step where detailed quantifiable pilot data for inspection use-case used for technology alternatives

4.4 Hybrid multi-criteria analysis methods: A step where multiple multi-criteria analysis methods are utilized together with respect to their own methodological strength (Yung-Chi Shen, 2010)

4.4 A Systematic Assessment Approach for Autonomous Inspection Technology Selection in the Oilseed Industry

The oilseed industry assumes great significance within the agricultural pursuits on a global scale and, most importantly, is being increasingly dependent on technological innovations to meet the demands for quality and operational efficiency. Autonomous inspection technologies should be given more emphasis as these technologies not only streamline activities in inspections that need to be conducted for maintaining product quality levels. This thesis research, therefore, provides a systematic procedure by which industry stakeholders or decision maker can choose such technologies in an informed way, strategically. A structured approach is proposed in the recommended framework, with each component designed carefully in such a way that it analyzes critically and identifies the most suitable technologies to include in oilseed processing operations.

The framework below in figure 9. outlines an orderly and complete structure allowing for scrupulous and unbiased evaluation and selection of technology. Within the framework is a complex flow-chart showing the key steps within the decision-making process, which is evaluated after detailed analysis of background study and literature on similar approaches, The important steps shall be further broken down in subsequent sections, for offering step-by-step guidance. It is important to note that, the preliminary steps before problem definition (STEP 1) are project initiative which eventually takes place after observations on many levels in the organization along with market research of available current solutions.

Each of the steps in this eight-step framework are interrelated, relying on the knowledge and analysis gained from the preceding stages to guarantee a comprehensive evaluation and selection procedure. Through meticulous organization of these stages, the framework ensures comprehensive coverage of all parts of the decision-making process, starting from the original problem description to the final selection, in accordance with both strategic goals and practical implementation requirements. The designed eight steps are product of background study analysis and other research papers based on the design approaches. The first step fulfilling the *REQ2.1* is based on defining the problem. Though in the research paper of hybrid emerging technology selection model (Yung-Chi Shen, 2010), the problem definition and scope are merged into single step, here the proposed approach will have two distinct steps (STEP 1 and STEP 2) due to the complex nature of methods and variety of scope and technology solutions in oilseed processing. It is important to find use-cases for autonomous inspection technologies (Hendrik Unger, 2018) in the defined scope to narrow down the list of technology alternatives which are available in the market. Therefore these two processes are alloted STEP 3 and STEP 4 respectively. Now that the technologies are identified and as technology selection is a multi-criteria problem, it is imperative to have a distinct step where relevant assessment criteria for autonomous inspection technology will be identified. Therefore, STEP 5 will fulfil *REQ1.5.*

For multi-criteria decision framework, with AHP, requires 4 distinct steps; 1) Hierarchical structuring of decision criteria with technology alternatives, 2) Pairwise comparisons to assess the relative importance of each criterion, 3) Calculation of priority weights and a consistency check to ensure reliable judgments, and 4) Synthesis of outcomes to aggregate the weights and produce a final ranking of alternatives (Akkineni V. Sivarama Prasad, 1990) but because the assessment criteria step is already defined in the STEP 5, the AHP is structured into three steps; The STEPS 6, 7 and 8 follow a multi-criteria decision making framework beginning from pairwise comparisons between criteria, calculating priority weights and finally concluding with weights aggregation to produce technology ranking. The aftermath of STEP 8, the technology ranking, will see the approval from key decision makers in the industry followed by a detailed implementation plan of technology deployment.

Incorporating the process elements of *REQ1.7* (Mohanty, 1998), the process begins with establishing a project initiative for technology selection, involving key stakeholders to define the problem accurately (STEP 1). This includes engaging various management levels during the problem definition and scope determination to ensure alignment with broader organizational goals (STEP 2). The expert sessions and process analysis for Identifying specific areas and use-cases for the inspection (STEP 3), followed by listing potential technological solutions (STEP 4), leverages both tacit and explicit knowledge across the organization (Mohanty, 1998). This ensures that the technology selection process aligned with operational needs. The final steps (5 to 8) of assessing criteria, comparing, and ranking technologies through AHP integrate stakeholder inputs and expertise, reflecting a participatory approach that improves the decision-making process. This study proposes interviews for assessing criteria, questionnaire survey for relative importance of criteria and finally expert sessions for giving weights to criteria.

Step 1: Defining the Technology Selection Problem

It is the proper and accurate definition of the problem that the technology is to solve which is the first step. The major challenge in this regard, within an oilseed sector framework, concerns the automation of the inspection process for more precision, speed, less risk of human error, and low labor cost. Selection of technology following this step will ensure that subsequent process will go straight towards the satisfaction of these specific operative needs, instead of getting lost in not so relevant technology options. A clear problem definition will save time and resources from inappropriate technologies, and guarantee the solution chosen meets the operational goals of the plant. *[REQ2.1]*

Process Element: Initial stakeholder meeting to establish key deliverables and objectives, focusing on automation needs for precision and cost-effectiveness in inspection processes.

Step 2: Define the Scope for Inspection Automation

Once the problem defined, the scope of automation needs to be worked out. It requires an understanding on which aspect oil seed inspection process can be automated as well as to what level this automation can be done. The industrial scope could be defined by various production units such as seed storage area and refinery. Understanding the scale of the work will help in identifying very specific technological needs, which, in turn, enable the elimination of technologies that will not work within the operational model of the facility. *[REQ1.2]*

Process Element: Interviews with the Industry leaders to gather insights on critical operations, and form robust decision-making team to find out other technology or process experts for next set data collection.

Step 3: Identifying Areas and Use-Cases for Inspection Procedures

Here is where detailed factory operational process analysis will be done to pinpoint the exact areas in which automation can be incorporated. This would also mean defining a few use positions at which inspection guidelines will matter for quality management—for instance, detecting impurities in oil seeds at various processing levels can be potential use-case applications.

The use-cases can be considered for asset integrity, equipment inspection or routine monitoring. Stating specific use cases then allows a focused methodology in selecting technology to ensure that the selected solutions assimilate well into ongoing operations while allowing effective improvement. *[REQ1.3]*

Process Element: Expert sessions to dissect each part of the plant operations, process irregularities identify key areas for automation, and define specific use-cases for technology application.

Step 4: Identifying the Technologies and Listing Alternatives

After listing use-cases, identify potential technologies that can meet those needs. It starts with a scan of offerings available in the current market, from mature technologies to novel innovations with an eye toward extracting competitive advantages from differentiation and early mover advantage. A list of technologies allows the selection process to run the gamut of possibilities and offers a broad base from which the best technology solution can be found. *[REQ1.6]*

Process Element: Conducting market research to list potential technology alternatives, followed by validation with technology experts to ensure the feasibility and effectiveness of the solutions considered.

Step 5: Identifying Technology Selection Criteria and Sub-Criteria

Technology selection is usually based and depend on multiple factors and assessing the potential of identified technologies with several criteria and sub-criteria. The criteria such as ease of integration, safety, technical specifications, and efficiency can be considered. In addition, sub-criteria might also be defined, to offer extra dimensions available to be used in the evaluation. The formulation of explicit criteria guarantees that every technology undergoes evaluation via a uniform and transparent process, which results in more impartial selection choices. *[REQ1.5]*

Process Element: Further interviews with experts to expand the scope of input, helping to define precise evaluation criteria and sub-criteria for the technology selection. Initial interviews with industry leaders can direct to these experts to form a decision-making team.

Step 6: Employ AHP (Analytical Hierarchy Process)

Using the Analytical Hierarchy Process from multi-criteria decision making, it provides pairwise comparison for the criteria showing their relative importance. What this would do is translate subjective judgments into quantitative values and then put them into a series of weights denoting priorities. AHP brings a structured mathematical methodology of decision making to help manage complex scenarios that have many balancing factors. *[REQ1.4]*

Process Element: Conducting a structured questionnaire survey among stakeholders to assess the relative importance of each criterion

Step 7: Calculate Weights using Eigen Vector Method

Weights of each criterion are calculated according to AHP through the eigenvector method. The weights obtained for each criterion become representatives of relative importance in the final decision-making process. Weights are appropriately calculated so the overall process of evaluation can follow the strategic goals and give a fair and equitable evaluation to all technologies. *[REQ1.4]*

Process Element: Hosting expert sessions to give weights to each technology, ensuring all aspects of each technology's potential impact are meticulously considered.

Step 8: Rank Technology Alternatives

Comparison and ranking of different technological alternatives shall further be based on the weighted criteria about which kind of technology best meets the predetermined criteria. Lastly, promote the final decision as to what sort of technology can be adopted. Ranking provides industry leaders an objective, actionable output of the selection process to allow for easy decision-making. *[REQ1.1]*

Process Element: Utilizing the calculated weights in a weighted sum model to rank the technology alternatives.

The figure for systematic assessment approach is shown below in figure 10. The design consists of a flowchart, consisting eight steps for technology selection including the set of activities or the process which are necessary to fulfil the requirements. The large rectangular nodes (in winter blue colour) represent the formal steps of the approach while arrow is used as connector for steps. The activities or process elements for fulfilling the deliverable of steps is inserted into the arrow between the steps. The small rectangular nodes (dark blue colour) represent the prerequisites and aftermath of the steps. While the approach is still quite formal, in chapter 5, it will be represented more explicitly with the specific case study involving the steps as well as real deliverables of steps in rectangular nodes.

FIGURE 10. SYSTEMATIC ASSESSMENT APPROACH

4.5 Conclusion Chapter 4

Chapter 4 presents a systematic approach for the assessment and integration of autonomous inspection technologies within the oilseed industry. This section examines the necessary steps for the effective application of these technologies, starting with the definition of the technology selection problem. The text emphasizes the significance of recognizing automation opportunities, detailing inspection use cases, and enumerating possible technologies for adoption. The Analytical Hierarchy Process (AHP) is highlighted as an essential tool for technology selection, facilitating the establishment of decision-making criteria and the weighting of these criteria to ensure objective evaluations.

This chapter presents a comprehensive multi-criteria decision-making framework that integrates technical and operational factors. This process entails the identification of appropriate technologies, the definition of specific selection criteria, and the application of a systematic approach to assess these technologies against established standards. The outcome is a prioritized list of technological options evaluated according to their efficacy and correspondence with industry requirements. The approach also mentions and explains why process elements and stakeholder involvement is necessary within the stepwise approach

Chapter 5 will validate the findings from the systematic assessment approach through a case study involving Cargill. This chapter signifies the transition to the final phase of the second diamond, termed the "deliver" phase. It will examine the practical implications and effectiveness of the proposed technologies, with the objective of demonstrating tangible benefits and the feasibility of their implementation in real-world contexts.

5. Empirical findings and Case Study

5.1 Introduction

Within a real-life setting at Cargill, this chapter will validate the proposed approach for selecting autonomous inspection technology in the oilseed industry. The procedure shall rigorously conform to the organized sequence specified in the flowchart, guaranteeing that each step is methodically executed to demonstrate the practical application and effectiveness of the approach. This systematic validation will determine the extent to which the chosen technology is in line with Cargill's strategic operational objectives and effectively tackles the current issues inherent in their inspection procedures. This validation will cover all aspects of the technology selection problem, starting from the initial definition to the ultimate ranking of technology alternatives. The objective of this work is to validate the theoretical models proposed in a real-world setting to verify their feasibility and provide concrete enhancements in efficiency and accuracy for Cargill's oilseed processing operations. The outcome of this activity will demonstrate a practical approach to incorporating sophisticated autonomous inspection technologies, highlighting the need of a systematic and evidence-based method for making decisions in industrial environments.

5.2 Company context

Cargill is an American food company, headquartered in Minnesota, offering a wide range of food products, ingredients, agricultural, and industrial solutions, apart from services around the world supported by their vast supply chain. The business was started by William Wallace Cargill in 1865 as a single grain storage facility located in Iowa, USA. Through 159 years of experience, Cargill has grown to be an international player in the food value chain across more than 70 different countries with over 125 unique selling markets. A workforce of around 160,000 leaders and team members who could successfully develop an extensive consumer base and economically add to developing the communities. In short, the company serves various services provided to different stakeholders, including agricultural producers, manufacturing concerns, retailers, food service clients as well as agri-food business, food processing business, the bio-business industry, animal nutrition business, and trading and risk management enterprises (About Cargill, 2024).

Cargill B.V. was established in the Netherlands as of 1959, where it continued with a commodity trading business until then. The group now focuses on manufacturing, processing, and distribution with trading in agricultural produce. The EMEA Global IT innovation team will provide information, guidance, and supervision for the thesis. The study will also be facilitated by aligning it with the overall operations of Cargill's oilseed extraction plants. The stakeholder involvement emphasizes the importance of active participation from Cargill employees and managers, highlighting their role in providing valuable insights, expertise, and practical experience related to the company's operations. Their involvement will contribute to the study of incorporating autonomous inspection technologies in the context of oilseed extraction plants.

5.3 Validation of Systematic Approach

5.3.1 Cargill Business case (problem definition and research scope (STEP 1 and 2)

From the Cargill business case, the primary goal was to eliminate manual inspection from the confined and hazardous areas they have in the plants. The problems such as employee retirements, workforce challenges and heavy costs for inspection were another set of challenges faced by the organization. The business case involves the elimination of manual inspection methods, especially at dangerous or inaccessible sites of Cargill facilities. Such a situation simply overburdens the employees and surely increases the chances of work-related accidents. Safety is then a big issue. In view of this, Cargill would surely not want those hazards but would want to make operations efficient with the help of autonomous inspection technologies. Business case concludes with the need of recommendations of technology and their selection methodology which in general aligned with the proposed approach.

Preliminary Interviews

The first preliminary interviews held at Cargill, with Project manager (*Participant A)* and Smart manufacturing leader (*Participant B)*, supported development of business case stating above business objectives and problem definition for implementing autonomous inspection technologies. The key stakeholders in Plant director (*Participant 6*) and Continuous improvement supervisor (*Participant 1*) were identified as industry leaders.

The second preliminary interviews with Plant director (*Participant 6*) and Continuous improvement supervisor (*Participant 1*) assisted in narrowing down the scope of implementing new autonomous inspection technologies.

> *"We are only looking into storage area of Cargill plants, as we already have solutions for other areas which are in pilot stage"*
>
> - *Participant 1*

> *"It would be handful to look into variety of technologies as the other areas like extractions have ATEX zones, and the ATEX certifications are quite expensive"*
>
> - *Participant 6*

The preliminary interview portions highlight strategic focuses and challenges at Cargill plants, particularly noting the exclusive emphasis on oilseed storage areas while recognizing the complexities in extraction zones designated as ATEX (certification for technologies for working in explosive areas) (ATEX and IECEX, 2024), which necessitate costly certifications. *Participant 1* notes that solutions for non-storage areas are progressing to pilot stages, indicating a phased approach to technology implementation. *Participant 6* emphasizes the financial and regulatory challenges associated with upgrading extraction zones, indicating the necessity for thorough cost-benefit analysis and technology scouting to identify cost-effective and compliant solutions in areas with strict safety standards. This indicates a comprehensive strategy involving prioritization, risk management, and innovation in plant operations.

Scope of case study

The major production line has several constituent parts, from storage and preparation to the extraction of oils, refining, and primarily setting the quality and productivity of the product. Oilseed storage area, is a significant aspect of Cargill's process which plays a vital role in the entire chain of efficiency. This business case investigates how these storage methods provide an opportunity not only to maintain seed quality but also to allow improving operational efficiencies along with the entire production chain. Cargill designed the facility to combine well with other production units, to allow for a smooth flow from storage to seed preparation and then extraction as may be required to maintain a good number of throughput levels. The visual representation of scope is shown below in figure 12.

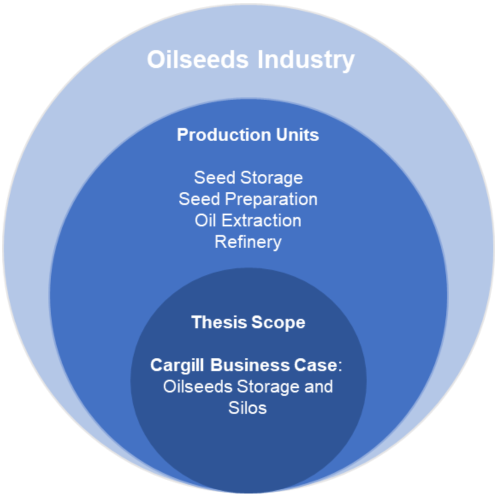

FIGURE 11. RESEARCH SCOPE

5.3.2 Process and inspection activities (Seed storage area at Cargill) (STEP 3)

In the preparation of this thesis, direct contact with Cargill, was made to gather much information regarding the procedures used for seed consumption and storage. Interviews were organized with important operational staff, and site visits at the premises of Cargill were conducted. These allowed for insights into practical aspects regarding the receiving and processing of seeds, which exactly corresponded to the techniques and technologies that Cargill was utilizing. Most importantly, Cargill allowed some of the internal process documentation and operational data to be copied, which improved understanding and, thus, accuracy in describing work flows in the thesis. This collaboration alone assured that the findings of the dissertation would be relevant and applicable but also increased its authenticity due to the involvement of actual industrial experience.

Detailed inspection activities and the use-cases elaborated in the thesis were pre-defined with the help of such pragmatic methodology, which was a result of thorough analysis of operational procedures carried out through extensive discussion with

Cargill personnel. Therefore, this approach guaranteed that necessities and dilemma about seed intake and storage were well documented to represent situations and practices as they are. Since the operational specifics are of a sensitive character with a lot of proprietary information involved, the thesis will not maintain confidential specific locations of inspections or exact methodologies elaborated on during interviews. The outcome of this would be to retain the integrity and relevance of the operational strategies of Cargill. A detailed process workflow for seed storage area in shown in figure 13.

Seed Intake and Storage Process

The seed intake process involves the arrival of seeds by ship, which are subsequently weighed by the IGMA and transported to storage facilities via a series of conveyor belts. A magnet positioned above the second conveyor removes iron particles from the seed flow. The seed storage system includes two large warehouses, each designed to accommodate a specific maximum capacity of sunflower seeds. These warehouses feature sloping roofs filled from above by chain conveyors, designed to match the natural angle of repose of sunflower seeds to optimize storage capacity. Due to their larger angle of repose, turnip seeds result in reduced storage efficiency within the same warehouses. Chain conveyors installed centrally within the warehouses facilitate the transport of seeds from storage to the processing plant. The intake and transport capacities are meticulously regulated to ensure consistent seed flow.

Seed Cleaning

The transportation of seeds from the storage warehouses to the seed cleaning facility is managed via additional chain conveyors. The primary objective of the seed cleaning process is the removal of large contaminants (e.g., stones, metal fragments, and lumps) and fine dust. At the conclusion of the initial conveyor, a magnet removes residual metal particles before the seeds enter the "de Marot" cleaning apparatus. This device effectively separates both fine and large particulate matter. The system includes an aspiration chamber where dust and fines are extracted by an air fan, collected in a decompression chamber, and then conveyed through a series of conveyors to dust filters. The filters utilize air pulses to dislodge accumulated dust, which is then directed to waste management systems.

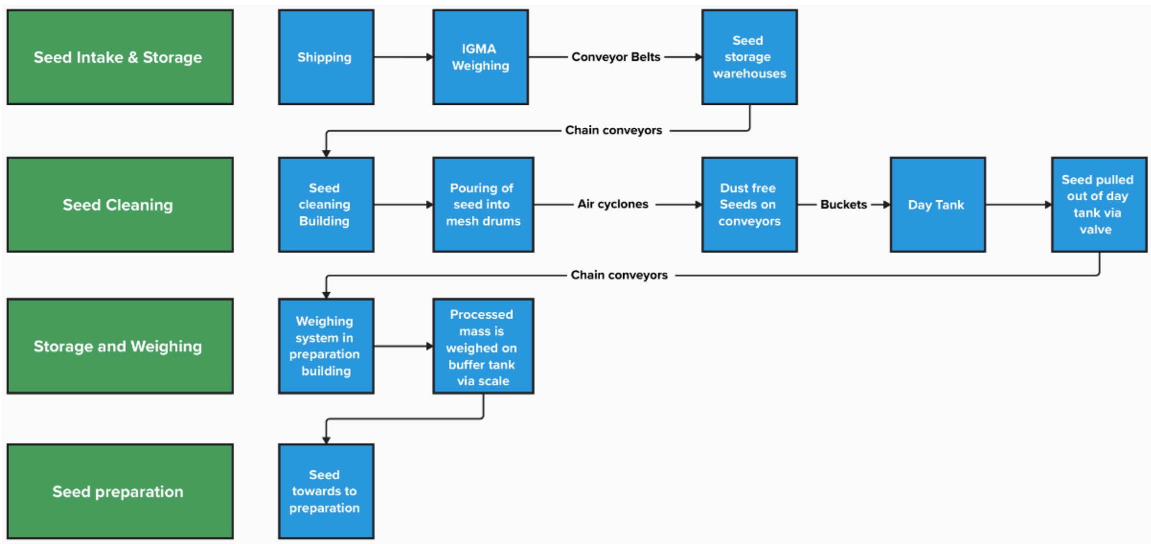

FIGURE 12. SEED STORAGE AREA: CARGILL (AUTHOR'S OWN INTERPRETATION)

Storage and Weighing

A day tank, with a substantial volume capacity, functions as a significant clean seed buffer, ensuring the stability of oil production processes despite fluctuations in seed intake or operational malfunctions. Seeds are drawn from the day tank through a PC-controlled valve and conveyed to the weighing system. This system features a small buffer tank equipped with an automatic scale, which measures seed mass in precise increments. The scale operates by filling a container to a specific mass, closing the valve, and then releasing the measured seed quantity for further processing. This method ensures accurate monitoring and control of the processed tonnage. The system maintains efficient processing rates for both turnip and sunflower seeds, thereby ensuring smooth operation and precise mass tracking throughout the production process.

Use-cases for inspection activities

1. Inspection of Belt and Chain Conveyors

Regular inspections of conveyor belts and chain conveyors are necessary to guarantee efficient functioning in seed processing installations. Automated monitoring systems have the capability to identify first indications of deterioration, inaccurate alignment, and possible obstructions that may impede the movement of seeds. By integrating sensors and AI-driven analytics, it is possible to consistently evaluate the state of these conveyors, which will then work as a preventive maintenance.

2. Inspection of the flat storage roof and structural integrity

Preserving the structural integrity of storage warehouses, particularly the state of flat storage roofs, is crucial to avoid financial losses caused by environmental hazards. Unmanned aerial vehicles or mechanized inspectors outfitted with cameras and sensors have the capability to conduct thorough examinations of these constructions, both from within and outside. By accurately detecting possible problems such as cracks, corrosion, or structural weaknesses, they can promptly carry out repairs and maintenance to guarantee the safety and integrity of the stored seeds.

3. Monitoring of Day Tank

Day tanks, which serve as temporary storage for seeds prior to processing, need careful surveillance to identify any leaks, fissures, or structural defects. Regular evaluation of these tanks can be conducted by automated monitoring systems that use ultrasonic sensors or visual inspection technologies. Engaging in proactive surveillance serves to preserve the integrity of the tanks, guaranteeing the absence of any interruptions in seed processing.

4. Inventory Checks and Mapping

Advanced technologies like drones or automated guided vehicles with high-resolution imaging can be employed within expansive warehouses to accurately map and visually record the quantities and dispersion of stored seeds. Implementing this strategy not only improves the precision of inventory control but also maximizes the use of space and logistics in the warehouse.

5. Assessment of Seed Cleaning Procedures

Monitoring the efficiency of the seed cleaning process can be significantly facilitated using automated systems. Systems of sensors and cameras can be deployed to consistently evaluate the functioning of essential cleaning equipment such as the "de Marot" apparatus and aspiration chambers. By implementing real-time monitoring, any remaining impurities or mechanical problems can be detected, allowing for prompt adjustments or maintenance to uphold the quality and effectiveness of the seed cleaning process.

6. Inspection of the tunnel area and conveyor located beneath the flat storage

Underlying flat storage areas, such as tunnels used by conveyors, are crucial locations that need frequent inspection to guarantee they are free from deterioration, damage, misalignment, or obstructions. 3D mapping by automated inspection technologies can offer comprehensive understanding of these regions, improving safety protocols and operational dependability.

5.3.3 Technology identification and listing alternatives (STEP 4)

The technologies identified were selected through careful consideration of available literature and web sources, supported by detailed evaluations conducted by technological experts at Cargill. The selection process targeted technologies that integrate with and align to the latest trends in unmanned aerial and ground vehicles, in relation to Cargill's operational requirements and strategic goals.

The specific models being adopted include the Elios 3, Intel Falcon 8+, Taurob Inspector, SuperDroid's Groundhog Pro, and ANYmal by Anybotics. These solutions are rugged, insulated, and specifically designed to enhance safety across industries of various types. Following this purposeful selection process, these technologies—though newly introduced—are appropriately suited for practical use within Cargill’s operational framework. The specifications for the five technologies are outlined below to briefly introduce each, along with their categories and alternative options.

Unmanned Aerial Vehicles (UAVs)

Elios 3 by Flyability ′

The Elios 3 is equipped with a protective enclosure to effectively absorb impacts, which are well-suited for manoeuvring through restricted areas. The device comprises a 4K Optical Camera affixed to a servo motor for precise angle modifications, enabling the recording of UHD video at 30 frames per second and the capture of 12MP still images. The inclusion of optional thermal imaging and intelligent LED lighting significantly improves its performance under different lighting conditions. The drone utilizes vision sensors for precision control and optional LiDAR for three-dimensional mapping, complemented by a 500 GB SSD for data retention. The power system of the aircraft incorporates an intelligent LiPo battery giving a flight duration ranging from 9 to 12.30 minutes. This battery is controlled by a ground control system that enables various flight modes to cater to different operational requirements (Elios 3 Digitizing the inaccessible, 2024).

FIGURE 13. ELIOS 3

Intel Falcon 8+ by Cyberhawk

The absence of a protective cage on the Intel Falcon 8+ highlights its suitability for open environments with very low direct impacts. This device facilitates high-resolution imaging by being compatible with cameras such as the Sony Alpha 7R, allowing 4K video recording. Specified inspections can also be conducted using thermal imaging. Navigating depends on GPS and sophisticated sensors that improve flight stability and safety. Data storage is enabled by an integrated solid-state drive (SSD). The Falcon 8+ utilizes cutting-edge lithium-polymer batteries with a substantial voltage capacity, controlled by an advanced ground control system that presents live video and data, and incorporates multiple flight modes to accommodate diverse situations (Falcon 8+ drone, n.d.). (Intel® Falcon 8+, 2024)

FIGURE 14. INTEL FALCON 8+

Unmanned Ground Vehicles (UGVs)

Taurob Inspector

The Taurob Inspector is specifically engineered to ensure stability on diverse terrains, featuring an extended arm that measures up to 1640 mm to enable inspections from many perspectives. The device is equipped with several 2K and 4K cameras, coupled with thermal and zoom cameras to improve the quality of detail capture. Navigation is facilitated using 3D LiDAR and audio sensors, which aid in the identification of environmental and operational irregularities. The UGV features a substantial battery capacity and rapid charging capabilities, ensuring optimal performance in dangerous conditions with rigorous safety certifications such as ATEX (ATEX and IECEX, 2024)._Durability is guaranteed by its wide operating temperature range and IP67 certification, while connectivity via 4G or WIFI enables extensive remote operation (THE INSPECTOR ROBOT, 2024).

FIGURE 15. TAUROB INSPECTOR

The Groundhog Pro, developed by Super-droid

The UGV features an anodized aluminium body and rubber wheels specifically engineered for manoeuvrability in diverse environments. It functions independently or by direct control, aided by Stereo LiDAR and dual stereo cameras for accurate navigation and avoidance of obstacles. The Groundhog Pro is equipped with a 360° camera to capture detailed environmental images and utilizes an NVIDIA Jetson AGX Orin for higher-performance computing requirements. The internal battery of the device has a runtime of up to 4 hours and incorporates autonomous charging capabilities, so enabling extended operations (Groundhog Standard, 2024).

FIGURE 16. GROUNDHOG PRO

ANYmal by Anybotics

THE ANYmal is specifically engineered to function in complex landscapes or terrains, with the ability to ascend stairs and manage slopes of up to 30 degrees. The system incorporates high-resolution cameras capable of capturing up to 4K images and a 20× optical zoom, in addition to a 16-channel LiDAR for precise environmental scans. An extensive temperature range is supported by the thermal camera, so enhancing its inspection capabilities. ANYmal's interchangeable Li-ion battery enables a range of 90-120 minutes of operating time, with complete recharging accomplished within a span of 3 hours. The adherence to rigorous safety and environmental criteria and the availability of optional 4G LTE connectivity guarantee that it is suitable for remote and autonomous operations in diverse environmental settings (ANYmal, 2024).

FIGURE 17. ANYMAL

5.3.4 Criteria for Technology selection (STEP 5)

This step delves into the empirical data acquired from semi-structured interviews, as well as the insights derived from archival archives, records, and direct observations carried out during the case study at Cargill. This information provides insight into the present status of the research. With the aim of addressing the third research question, the interviews were specifically crafted to ascertain the criteria used for technology selection. A thorough transcription and analysis of the interviews have been conducted using the qualitative data analysis software, Atlas.ti, to accurately assess and interpret the responses.

The interviews involved a diverse group of participants, each holding specific roles within the organization, which provided different viewpoints on technology assessment and selection. The list of participants was generated through a snowball sampling method where initial interviewees with Plant director and Continuous Improvement Senior Supervisor who directed to the expertise of other participants, which were later categorized into three clusters. List with respect to cluster of interviewees are explained below:

Technology and Process Innovation: This group combines individuals focused on innovation and those with specialized technology expertise. It included;

Smart Manufacturing Process Expert (*Participant 3*): Focuses on implementing innovative manufacturing processes.

Digital Operations Leader (*Participant 4*): Specializes in managing manufacturing operations and digital workflows.

Smart Manufacturing Leader (*Participant 10*): Oversees smart manufacturing initiatives.

Robotics Engineer (*Participant 11*): Specializes in the integration and optimization of robotics within manufacturing.

Reliability Excellence Leader (*Participant 5*): Concentrates on enhancing reliability and maintaining high standards in technology applications.

Operational and Plant Management: This cluster comprises senior managers responsible for overseeing plant operations and ensuring the strategic implementation of new technologies. It included;

Plant Director (*Participant 6*): Manages multiple plant sites, focusing on operational efficiency and effective technology deployment.

Senior Reliability Engineer (*Participant 7*): Provides expert advice on reliability engineering across global operations.

Engineering Manager (*Participant 8*): Handles the engineering aspects within plant operations, promoting technological advancements.

Quality and Compliance: This group consists of roles that ensure technologies adopted adhere to compliance standards and contribute to continuous improvement. It included:

Reliability Engineer (*Participant 2*): Focuses on ensuring the reliability of technology in seed processing operations.

Quality Assurance Leader (*Participant 9*): Oversees quality assurance and regulatory compliance for technologies in use**.**

Continuous Improvement Senior Supervisor (*Participant 1*): Oversees and directs continuous improvement initiatives.

Interviewee (Cargill)	Designation
Participant 1	Continuous Improvement Senior Supervisor
Participant 2	Reliability engineer
Participant 3	Smart Manufacturing Process Expert
Participant 4	Digital Operations Leader
Participant 5	Reliability Excellence Leader
Participant 6	Plant Director
Participant 7	Senior Reliability Engineer
Participant 8	Engineering Manager
Participant 9	Quality Assurance Leader
Participant 10	Smart Manufacturing Leader
Participant 11	Smart Manufacturing Robotics Engineer
Participant A	Project Manager
Participant B	Smart Manufacturing Leader

TABLE 1. INTERVIEWEES

Interview Analysis

After conducting thorough interviews, a detailed thematic analysis was conducted out to summarize and organize the significant qualitative data collected. An exhaustive analysis identified relevant themes and patterns in the interview material. A systematic presentation of the data will be provided, emphasizing the ramifications and insights obtained from each unique theme uncovered during the investigation. The main themes uncovered were Usability, Safety Standards, Operational Efficiency, Financial Viability, Legal and Regulatory Compliance, Technical Capability, and Technological Maturity. This approach ensures that the results are displayed in a clear and structured manner, ensuring a precise understanding of the specific conclusions associated with each theme category. As certain codes are integrated with others to avoid duplication, not all codes may be categorized under a single subject. Selected quotations that distinct viewpoints are referenced, with a detailed overview provided in Appendix 3.

The findings of the interviews and the criteria identification are given below:

C1. Usability

> *"So, the usability, right, If you need a very specialized person to implement these kind of technologies, then that will cost more."*
>
> *- Participant 4*

> *"Looking at a new technology, there are things that you need to check, like user friendliness, usability, ergonomic stuff, ergonomic stuff, or service agreements with a partner".*
>
> *- Participant 7*

> *"So, if it's as simple as doing like a video game, remote control, taking the robot and putting it in there with basic training and we can train X amount of people to do it."*
>
> *- Participant 3*

In an analytics study on technology usability, *Participant 4* highlights the cost implications of requiring specialized personnel for technology implementation, suggesting that more intuitive designs could reduce these costs and barriers to adoption. *Participant 7* focuses on ergonomic design and user-friendliness, essential for preventing fatigue and injuries while enhancing user efficiency and satisfaction. *Participant 3* emphasizes the importance of simplicity in training, advocating for technology that is as easy to learn as playing a video game, which could decrease onboarding time and training costs. Together, these insights could be integrated into a detailed analysis that evaluates the overall impact of usability on technological adoption rates, operational integration, cost-efficiency, and user satisfaction within various organizational contexts**.**

C2. Financial Viability

> *"First of all, if the technology can avoid that we need to build a scaffolding or we can avoid that we need to have an entry, that would be great."*
>
> *- Participant 5*

> *"The second thing is the cost, right? That is always a consideration with all businesses. And most importantly, if you're solving a problem that has to do with your operations, there should be a return on invested capital."*
>
> *- Participant 3*

Financial Viability delves into the economic considerations essential for adopting new technologies, as expressed by P*articipants 5 and 3. Participant 5* highlights the cost-saving potential of technologies that eliminate the need for physical structures like scaffolding or entry requirements, thereby reducing setup and operational costs. This aspect is crucial when considering the Operational Inspection Costs, which involve the recurring expenses related to maintaining and operating the technology efficiently. *Participant 3* underscores the significance of evaluating the Technology Investment Cost—the initial capital outlay should be justified by a tangible return on invested capital, emphasizing that any investment should directly address and potentially solve operational inefficiencies. Furthermore, the Training Requirement plays a pivotal role in Financial Viability as it influences both the initial and continuous financial outlays for human resources, affecting overall cost-effectiveness and efficiency of technology integration. Additionally, Contractual and Software Licensing Expenditure is examined to account for the often-overlooked costs associated with acquiring and maintaining software licenses necessary for the operation of new technologies. This comprehensive financial assessment ensures that technology investments are not only justified in terms of capabilities but also align with broader financial strategies and operational budgeting.

C3. Safety Standards

> *"The technology should be safe to operate. It should prevent people or pedestrians to be hit by the device."*
>
> *- Participant 8*

Safety Standards are a critical consideration when evaluating the introduction of new technologies, as emphasized by *Participant 8* who insists on the paramount importance of operational safety. The participant specifically mentions that technology should be designed to prevent accidents, such as avoiding collisions with pedestrians, which directly relates to Industrial Safety. This criterion involves ensuring that technology adheres to rigorous industry-specific safety protocols to avert workplace incidents, which is vital for safeguarding employees and maintaining a secure work environment. Ensuring compliance with these standards not only helps in minimizing the risk of accidents but also reduces legal liabilities for the organization. Furthermore, adherence to safety standards enhances the reliability of operations by ensuring that technologies are not only efficient but also consistently safe, thereby supporting sustained operational performance and trust in the use of new technologies. Hence, with the goal of eliminating manual inspection methods and successful implementation of new autonomous technologies, Safety has an utmost importance.

C4. Operational Efficiency

> *"Versatility as well. I mean, mostly the decision makers want one tool to be used on multiple occasions or at multiple places".*
>
> *- Participant 4*

> *"So that is really important to not necessarily identify all the details of the problem that it might solve, but the main metrics, yes, that this technology would help us improve. And that might be efficiency, repeatability, safety and productivity, less downtime."*
>
> *- Participant 9*

Operational Efficiency is a key factor in the adoption and integration of new technologies, as highlighted by *Participant 4* and *Participant 9*. *Participant 4* emphasizes the importance of versatility in technology, suggesting that decision-makers prefer tools that can be applied in multiple scenarios or locations, which directly aligns with the sub-criterion of Multi-Setup Compatibility. This involves evaluating whether the technology can be adapted to different configurations or operational setups, improving its utility and cost-effectiveness. *Participant 9* discusses the broad impacts of technological adoption on key performance metrics such as efficiency, safety, and productivity, while particularly stressing the importance of Downtime Minimization. This sub-criterion focuses on the technology's ability to reduce non-operational periods, crucial for maintaining continuous and efficient workflows. Additionally, Inspection Adequacy is assessed to ensure the quality and comprehensiveness of technology-driven inspections, which affects overall operational quality. Finally, Measurement Repeatability is crucial as it ensures that the technology provides consistent and reliable results under varying conditions, further supporting the operational efficiency of the organization. Together, these aspects contribute to a systematic improvement of performance and productivity through the strategic application of technology.

C5. Legal and Regulatory Compliance

> "*We run into challenges where we can have the technology available and we can use it in country 1, but for us to use the same technology in country 2 is a challenge because of different laws, So, legal and the regulation stuff."*
>
> *- Participant 9*

> *''if we want to go for an external inspection, it is harder if the airport is nearby.''*
>
> *- Participant 4*

> *"Like obviously these drones and the technologies are somewhere connected to some servers, which sometimes can, cannot be in control of us"*
>
> *- Participant 4*

Legal and Regulatory Compliance is a pivotal aspect of deploying technology across various jurisdictions, as illuminated by the challenges faced by *Participant 9* and *Participant 4*. *Participant 9* identifies the complexity of using the same technology in different countries due to varying legal frameworks, underscoring the importance of Adherence to National Standards, which ensures that technology meets specific local regulations. This is crucial for the seamless and lawful operation of technology across different legal environments. *Participant 4* mentions the complications of conducting external inspections when the oilseed plants are near airports, hinting at the necessity for specific compliance measures. Additionally, as stressed by *Participant 4* again, Cybersecurity Assessment plays a critical role by evaluating the technology's ability to defend against digital threats, which is increasingly vital in safeguarding sensitive information and maintaining operational integrity in our interconnected digital world. Collectively, these sub-criteria ensure that the technology not only aligns with but is robust enough to withstand the legal and regulatory challenges it might face during implementation and use.

C6. Technical Capability

> *"Ideally the technology should be able to operate on not so perfect environment".*
>
> *- Participant 2*

> *"I think it's important that the measurement is repeatable. So, if you have exactly the same situation that and you do the measurement 10 times that you get 10 times almost the same result".*
>
> *- Participant 3*

> *"For the technology, you can make a distinguish between explosion proof or not, you know, because some things you have in the next scenario, you need that explosion proof, means ATEX certified".*
>
> *- Participant 10*

> *"So like a ground robot should also go around multiple floors in the plant, climb stairs and make its way through uneven surfaces".*
>
> *- Participant 10*

Technical Capability is essential for ensuring that technology performs effectively under various conditions, as expressed by *Participant 2*, *Participant 3*, and *Participant 10*. *Participant 2* stresses the need for technology to operate reliably in less-than-ideal environments, which ties directly into Adaptive Environmental Functionality. This sub-criterion assesses how well the technology adapts to different environmental conditions, ensuring robust performance even in adverse settings. *Participant 3* highlights the importance of Measurement Repeatability, noting that consistent results are crucial when the same measurements are taken multiple times under identical conditions, reflecting the technology's precision and reliability. *Participant 10* addresses the need for specialized technical features like explosion-proof capabilities with ATEX certification (ATEX & IECEX, 2024), and particularly in hazardous environments. *Participant 10* also examines how the technology performs in difficult geographical or hazardous conditions, ensuring safety and functionality where risks are elevated, which can be added as a sub-criterion of Challenging Terrain Accessibility Collectively, these aspects of Technical Capability ensure that the technology not only meets basic functional requirements but also excels in specialized and demanding scenarios.

C7. Technological Maturity

> *It is I think a standard kind of scale, so you can ask a vendor in the tech maturity scale, where do you see your product being today?"*
>
> *- Participant 3*

> *"We will be interested in in buying something which is already proven"*
>
> *- Participant 5*

> *"If somebody had a score and a table, it says that it has already been proven and it works in these environments and these conditions, yeah, that would be that would be valuable rather than us spending the time and the money and the resources to improving".*
>
> *- Participant 6*

Technological Maturity is a critical measure of a technology's development and its validation in real-world settings, as emphasized by *Participant 3*, *Participant 5*, and *Participant 6*. *Participant 3* suggests using a standard scale to inquire about a product's maturity from vendors, directly relating to the Technology Readiness Level (TRL), which assesses a technology's readiness from initial concept (TRL 1) to proven application (TRL 9) (Manning, 2023). This scale helps in understanding the preparedness of technology for widespread use and its reliability based on prior successes. Participant 5 expresses a preference for technologies that are "already proven," which underscores the significance of high TRLs in making purchasing decisions, as these levels indicate a technology's effectiveness and reliability. *Participant 6* values the presence of a clear, quantifiable measure (like a score or table) indicating a technology's performance in specific environments and conditions. This test evaluates how well the technology integrates with existing systems, which is essential for ensuring that new technologies can be seamlessly incorporated into current operational frameworks without extensive modifications or upgrades, which can be called as its Sensor and Software Integration Capability Collectively, these aspects of Technological Maturity provide a framework for assessing a technology's viability, integration potential, and readiness, thereby guiding strategic investment and implementation decisions.

The analysis presents an examination of autonomous inspection technology selection criteria based on interviews with key stakeholders at Cargill. Major themes identified include Usability, Financial Viability, Safety Standards, Operational Efficiency, Legal and Regulatory Compliance, Technical Capability, and Technological Maturity. These themes highlight the importance of versatility, cost-effectiveness, safety, legal compliance, and technological readiness in the decision-making process. Each criterion reflects the need for technologies that are not only advanced and reliable but also align with organizational goals and regulatory standards, ensuring effective and efficient integration into existing systems. The next point will display the code tree, illustrating how these criteria emerged from the sub-criteria, providing a visual representation of the thematic structure and relationships within the data.

Code tree

The infographic below in figure 18. visually represents the hierarchical structure of criteria essential for autonomous inspection technology selection, utilizing a code tree format to illustrate the relationships from sub-criteria to overarching themes. Each criterion—Usability, Safety Standards, Operational Efficiency, Financial Viability, Legal and Regulatory Compliance, Technical Capability, and Technological Maturity—is represented by a node that branches out into detailed sub-criteria. This layout aids in understanding how specific operational details, such as 'Ease of Use' under Usability or 'Explosion Safety' under both Safety Standards and Technical Capability, contribute to broader evaluation themes. This methodical arrangement highlights the interconnectedness of various factors, emphasizing a structured approach to technology assessment that ensures comprehensive and contextually relevant analysis.

FIGURE 18. CODE TREE

5.3.5 Employ Analytical Hierarchy Process (STEP 6,7,8)

To apply the Analytical Hierarchy Process (AHP) for ranking the autonomous inspection technologies based on multiple criteria, there are several steps. The steps include structuring the hierarchy, conducting pairwise comparisons using scale, synthesizing these comparisons to derive weights, and then using these weights to rank the technologies. The hierarchy is shown in figure 19.

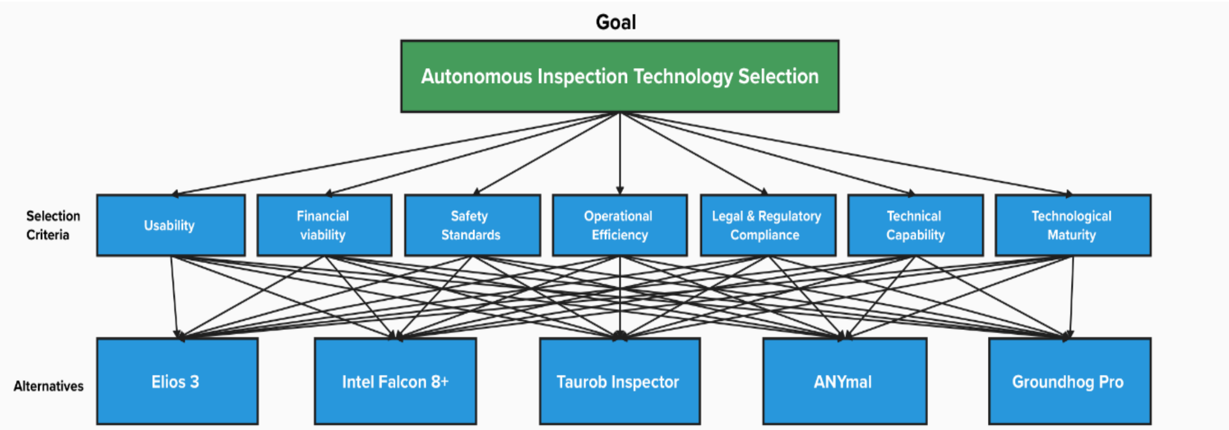

FIGURE 19. AHP HIERARCHY

Pairwise comparison and Matrix normalization (STEP 6)

Goal: Select or rank the technology from best to worst.

Criteria: Usability, Financial Viability, Safety Standards, Operational Efficiency, Legal and Regulatory Compliance, Technical Capability, Technological Maturity.

Technology Alternatives: Elios 3, Intel Falcon 8+, Taurob inspector, ANYmal and Groundhog Pro.

The Analytical Hierarchy Process is a structured decision-making technique used to solve complex decisions involving multiple criteria. Introduced in the 1970s by Thomas L. Saaty, AHP does have its roots in mathematics and psychology; thus, this process allows a decision-maker to decompose a particular issue, about which a decision needs to be taken, into a hierarchy of smaller sub-criteria. This analysis applies specifically to technology selection (Saaty T. L., 2005)

There are several steps for performing AHP, hence they are given below;

The Saaty Scale

The Saaty scale forms an integral part of AHP, providing the numerical frame against which decision elements can be compared in pairs. This scale goes from 1 to 9, where:

1 means that both criteria have equal importance.

3 indicates that one element is slightly more important than the other.

5 means one element is very important than the other.

7 one element is highly important than the other.

9 means extremely important.

2, 4, 6, and 8 serve as intermediate values for finer distinctions and scale transforms subjective judgments into a quantifiable format, allowing for the systematic comparison of criteria. Questionnaire was conducted with paired comparison scale to assess the relative importance of seven criteria by comparing them pairwise, resulting in 21 comparisons. 10 Cargill employees participated, rating their preferences for each pair. Their responses were averaged to create a pairwise matrix as shown in table 1.

Pairwise Comparison Matrix

AHP moves on to the development of a pairwise comparison matrix. Two items - technology, criterion, etc. are juxtaposed for the attribute in question and values are entered in the matrix through the Saaty scale and the judgments are entered into the matrix using the scale. The matrix is typically of the order $n \times n$, where n is the number of elements being compared. If three autonomous technologies T_1, T_2, and T_3 are being compared, the pairwise comparison matrix A would be structured as follows:

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} \\ \frac{1}{a_1} & 1 & a_{23} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 \end{pmatrix}$$

Where a_{ij} represents the relative importance of technology T_i over T_j.

Comparison Matrix Normalization

Normalizing a pairwise comparison matrix returns the relative weights of the elements with respect to each other. The normalization is achieved by dividing each element of the matrix by the sum of the column elements, yielding a normalized matrix N. The pairwise matrix with relative preferences of all 7 criteria from average of questionnaire input is shown in table 2. For the matrix A :

$$N_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

Criteria	Usability	Financial Viability	Safety Standards	Operational Efficiency	Legal Compliance	Technical Capability	Technological Maturity	**Priorities**
Usability	1.0	2.0	9	0.5	3	0.5	0.2	**0.085**
Financial Viability	0.5	1.0	4	0.5	4	0.333	0.143	**0.12**
Safety Standards	0.111	0.25	1	0.143	1	0.167	0.111	**0.361**
Operational Efficiency	2.0	2.0	7	1.0	4	4.0	0.333	**0.051**
Legal Compliance	0.333	0.25	1	0.25	1	0.167	0.111	**0.287**
Technical Capability	2.0	3.0	6	0.25	6	1.0	0.333	**0.073**
Technological Maturity	5.0	7.0	9	3.0	9	3.0	1.0	**0.023**

TABLE 2 PAIRWISE COMPARISON MATRIX

The "Priorities" in the table 1. represents the normalized weights of each criterion, reflecting their relative importance in the decision model. The brief interpretation of the section: 1) Safety Standards (0.361) is the most important criterion based on this analysis. 2) Legal Compliance (0.287) and Financial Viability (0.12) also hold significant weight 3) Usability (0.085), Technical Capability (0.073), Operational Efficiency (0.051), and Technological Maturity (0.023) are relatively less critical.

Calculating Weights (Priority Vector) (STEP 7)

The priority vector w for each technology is calculated by averaging the normalized values in each row of the normalized matrix N. This vector represents the relative importance of each technology in the context of the criteria being considered.

$$w_i = \frac{\sum_{j=1}^{n} N_{ij}}{n}$$

In the above formula, w_i is the weight for the i-th technology. Experts' sessions were conducted with one of the interviewees to give weights to the technologies with respect to the criteria. All the tables with respect to criteria are given below:

Usability	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	2	2	2	5	0.352
Intel Falcon 8+	0.5	1	4	1	4	0.246
Taurob Inspector	0.5	0.25	1	0.25	1	0.089
Anymal	0.5	1	4	1	4	0.246
Groundhog Pro	0.2	0.25	1	0.25	1	0.067

Table 3 Usability

Financial Viability	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	1	3	3	3	0.333
Intel Falcon 8+	1	1	3	3	3	0.333
Taurob Inspector	0.333	0.333	1	1	1	0.111
Anymal	0.333	0.333	1	1	1	0.111
Groundhog Pro	0.333	0.333	1	1	1	0.111

Table 4 Financial Viability

Safety Standards	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	2	4	1	7	0.346
Intel Falcon 8+	0.5	1	3	0.5	3	0.226
Taurob Inspector	0.25	0.333	1	0.33	1	0.078
Anymal	1	2	3	1	3	0.287
Groundhog Pro	0.143	0.143	1	0.333	1	0.063

Table 5 Safety Standards

Operational efficiency	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	0.333	0.333	0.5	2	0.108
Intel Falcon 8+	3	1	4	1	3	0.326
Taurob Inspector	3	0.25	1	0.333	4	0.171
Anymal	2	1	3	1	8	0.337
Groundhog Pro	0.5	0.333	0.25	0.125	1	0.059

Table 6 Operational Efficiency

Technical Capability	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	1	3	1	5	0.281
Intel Falcon 8+	1	1	3	1	5	0.281
Taurob Inspector	0.333	0.333	1	0.333	3	0.108
Anymal	1	1	3	1	5	0.281
Groundhog Pro	0.2	0.2	0.333	0.2	1	0.051

Table 7 Technical Capability

Legal compliance	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	1	1	1	1	0.2
Intel Falcon 8+	1	1	1	1	1	0.2
Taurob Inspector	1	1	1	1	1	0.2
Anymal	1	1	1	1	1	0.2
Groundhog Pro	1	1	1	1	1	0.2

Table 8 Legal Compliance

Technology Maturity	Elios 3	Intel Falcon 8+	Taurob Inspector	Anymal	Groundhog Pro	Priorities
Elios 3	1	1	2	2	2	0.286
Intel Falcon 8+	1	1	2	2	2	0.286
Taurob Inspector	0.5	0.5	1	1	1	0.143
Anymal	0.5	0.5	1	1	1	0.143
Groundhog Pro	0.5	0.5	1	1	1	0.143

TABLE 9 TECHNOLOGY MATURITY

Synthesis of Results and Technology Ranking (Step 8)

After computing the weights for each criterion and each technology, a weighted sum model is applied to determine the overall scores for each technology. The final score S_j for each technology T_j is calculated by summing the products of the weights of each criterion and the corresponding weights of the technologies under that criterion:

$$S_j = \sum_{i=1}^{m} w_i \times w_{ij}$$

In the above formula, w_i is the weight of the i-th criterion, and w_{ij} is the weight of the j-th technology under the i-th criterion.

S_j = 0.09 * [Usability] + 0.12 * [Financial viability] + 0.36 * [Safety Standards] + 0.05 * [Operational efficiency] + 0.29 * [Legal compliance] + 0.07 * [Technical capability] + 0.02 * [Technological maturity]

The technologies are ranked based on their final scores S_j. Using priority vector for each technology with respect to criteria weights, technologies are ranked. The technology with the highest score is considered the most suitable according to the criteria and weights defined in the AHP process.

Consistency check

AHP requires that the pairwise comparisons being made have consistency. To observe this consistency, the ratio of consistency is calculated. This ratio can be found by the following formula below. RI is Random Index, which depends on the number of elements n. According to Saaty, CR value of less than 0.1 indicates an acceptable level of consistency (Saaty R. , 1987).

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

The consistency ratios, which are generally low, suggest a coherent set of judgments, thus validating the results of the evaluation. Usability has a consistency ratio of 0.048, demonstrating moderate consistency in judgments. Financial Viability, Legal Compliance and Technological Maturity register a consistency ratio of 0.0, indicating perfect consistency among the evaluations. Safety Standards show a consistency ratio of 0.05, suggesting good consistency. Operational Efficiency has a consistency ratio of 0.089, which is slightly higher but still indicates acceptable consistency. Technical Capability is assessed with a consistency ratio of 0.0094, reflecting very high consistency in the evaluations. These ratios help ensure that the pairwise comparisons within each criterion are logically sound and reliable. Additionally, the document includes a sensitivity analysis in Appendix 6, focusing on how variations in the evaluation of Safety Standards for Elios 3, particularly against options like Anymal and Intel Falcon 8+, could affect its scoring. This analysis provides a detailed framework for structured decision-making, allowing for a detailed comparison and strategic choice among technological options

Results

The Analytic Hierarchy Process (AHP) was used to evaluate various technological options across several criteria. The criteria used and their corresponding weights are Usability (0.09), Financial Viability (0.12), Safety Standards (0.36), Operational Efficiency (0.05), Legal Compliance (0.29), Technical Capability (0.07), and Technological Maturity (0.02). The analysis focuses on five options: Elios 3, Intel Falcon 8+, Taurob Inspector, Anymal, and Groundhog Pro. Safety Standards are the most heavily weighted criterion, significantly influencing the overall priorities assigned to the options, with Elios 3 ranking highest in this category. This boosts its overall priority score to 0.285, making it a strong candidate. Intel Falcon 8+ follows with a score of 0.244, demonstrating competitive capabilities. Meanwhile, Groundhog Pro, scoring the lowest overall priority at 0.109, appears to lag in essential areas compared to other options. The ranking is shown in the table below.

Technology	Priority Score	Ranking
Elios 3	0.285	1
Intel Falcon 8	0.244	2
ANYmal	0.236	3
Taurob Inspector	0.126	4
Groundhog Pro	0.109	5

TABLE 10 TECHNOLOGY RANKING

.The application of the systematic approach with the help of AHP in this research not only improves decision-making but also strategically aligns technological investments with core business objectives, delivering multiple layers of value across the organization.

By employing AHP to systematically evaluate various technological options like Elios 3, Intel Falcon 8+, Taurob Inspector, Anymal, and Groundhog Pro against detailed criteria including Usability, Financial Viability, Safety Standards, Operational Efficiency, Legal Compliance, Technical Capability, and Technological Maturity, the process ensures a comprehensive assessment. The differential weighting of these criteria reflects their relative importance to the organization's specific needs, emphasizing areas such as Safety Standards—which received the highest weight of 0.36. This focus on safety is particularly beneficial for industries where compliance and risk management are crucial, potentially reducing accident-related costs and enhancing worker safety. Elios 3's leading scorer in Safety Standards, contributing to its highest overall priority score of 0.285, signifies its role as a catalyst in promoting a safer working environment. This could lead to lower insurance premiums, fewer workdays lost to injury, and an improved reputation for safety that can be crucial in client negotiations and bidding for new contracts. Furthermore, the insights gained from AHP help in optimizing budget allocation by directing funds toward technologies that offer the highest value return. Investing in high-ranking options like Elios 3 and Intel Falcon 8+ could drive operational efficiencies, foster innovation, and maintain competitive advantage through superior technological capabilities. This targeted investment approach minimizes wastage of resources on less effective solutions and accelerates the integration of high-impact technologies into core operations. In addition, the detailed analysis provided by AHP aids in transparent reporting and stakeholder communication. By clearly demonstrating why certain technologies were prioritized based on quantifiable and weighted criteria, the process supports more informed decision-making among stakeholders, including investors, who may seek assurance that capital is being deployed effectively.

Lastly, this approach to technology evaluation and selection enhances adaptability. As business environments evolve and new technologies emerge, the criteria and their weights can be adjusted to reflect changing priorities, ensuring that the organization remains agile and responsive to market dynamics. This adaptability is crucial for sustaining long-term growth and responding proactively to industry challenges and opportunities. Thus, the business value of employing AHP in technology assessment extends well beyond the immediate benefits of risk management and operational efficiency. It fosters a culture of informed and strategic investment, enhances stakeholder confidence, and secures a competitive position in rapidly changing markets.

The detailed systematic approach (for Cargill) is shown below. It is also divided into two parts (Part A and B) further for better visual representation.

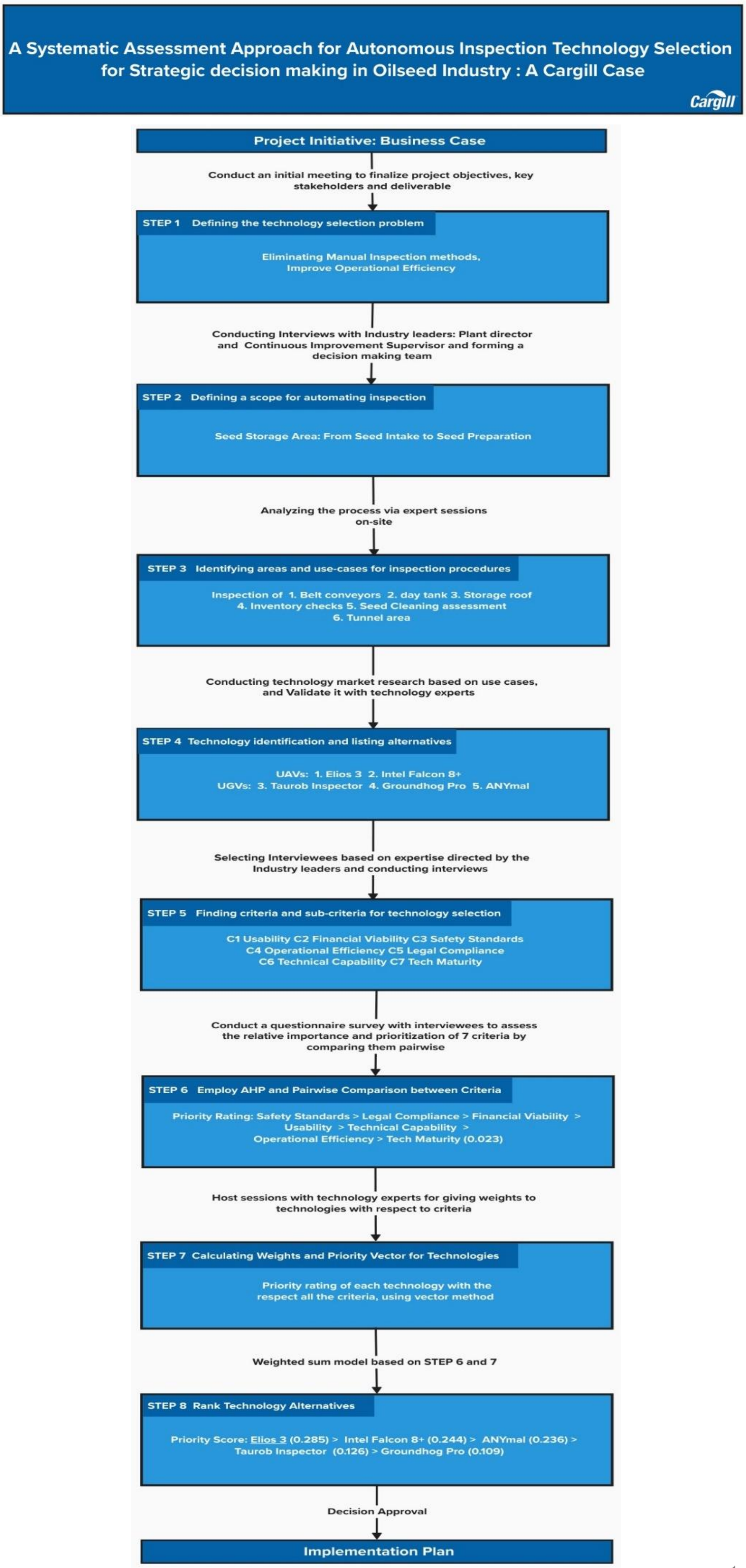

FIGURE 20. SYSTEMATIC ASSESSMENT APPROACH

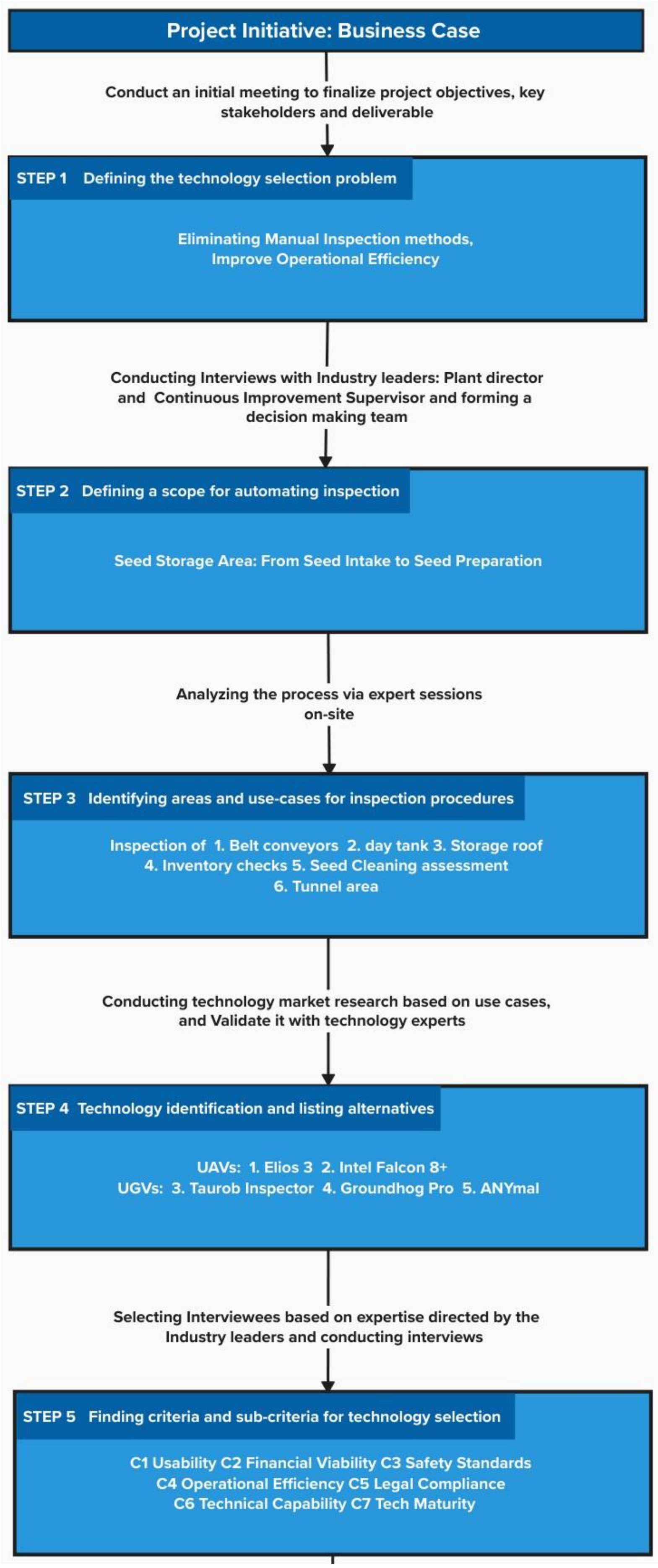

Figure 21. Approach Part A

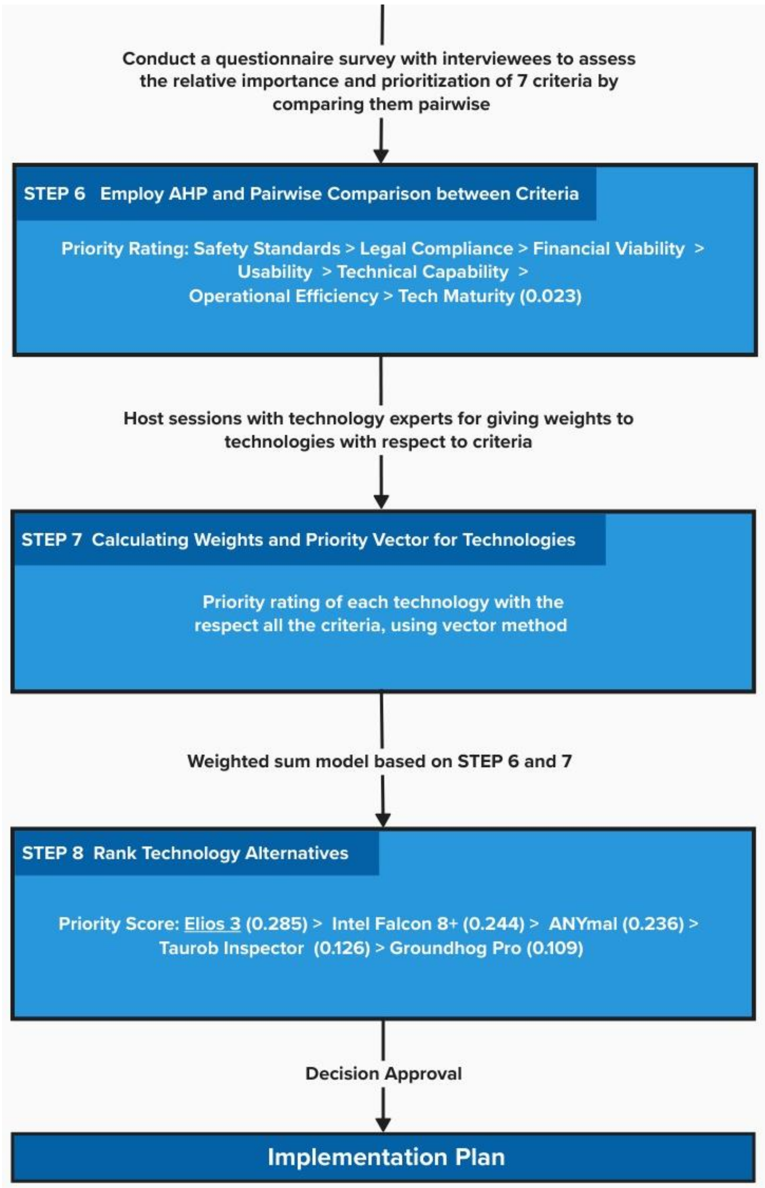

FIGURE 22. APPROACH PART B

5.4 Conclusion chapter 5

The conclusion of the chapter on the validation of the systematic approach within the Cargill business case encapsulates a significant stride towards integrating autonomous inspection technologies in hazardous operational areas. This strategic shift not only aims to enhance operational safety and efficiency but also adeptly addresses the escalating challenges posed by manual inspections amidst an aging workforce and escalating operational costs. Through a meticulous process that involved defining the problem scope, engaging with on-ground personnel via interviews, and conducting site visits, the study was able to capture a comprehensive understanding of the operational needs and challenges at Cargill. This foundational work set the stage for a robust application of the Analytic Hierarchy Process (AHP) for technology evaluation. The implementation of AHP facilitated a structured decision-making process where multiple criteria such as usability, safety, and financial viability were evaluated, thus ensuring a holistic assessment of potential technologies. This approach underscored the importance of a systematic, criteria-based evaluation in making informed decisions that align with organizational strategic goals and operational requirements. Moreover, the findings from the AHP analysis, supported by low consistency ratios, validate the decision-making process's reliability and coherence. Such analytical rigor ensures that the selected technologies not only fit Cargill's specific operational context but also offer a roadmap for future technology integrations across similar industrial settings.

In conclusion, this chapter not only highlights the effectiveness of a systematic approach to technology integration in complex industrial environments. The insights gained and the methodologies applied provide a valuable framework for Cargill and similar companies looking to navigate the complexities of modern industrial operations.

6. Conclusion, Recommendations and Discussions

6.1 Conclusion

The following section concludes the research gathered from project methodologies by referring to the research questions and design objective of the thesis.

RQ1: What are the current processes and inspection points in oilseed processing, and how can they be described?
The remarkable lack of a systematic literature review on oilseed processing has hence driven the research to focus on a major gap. The relative shortage of comprehensive scholarly works can heighten the scholarly value of this research, turning it into a step toward standardization of knowledge in an area considered vital to agricultural and manufacturing sectors worldwide. Oilseed processing is a multistoried sector, embracing together many aspects of technologies and operations from basic extraction of oil from seeds to sophisticated techniques used in refining and quality control. Such a gap not only hinders theoretical understanding upon which innovation must be founded, but also restricts the opportunities for improvement in operations within the industry.

Accordingly, the thesis categorizes the major units of oilseed industry into four distinct parts; seed storage and cleaning; seed preparation; seed extraction; and refinery and utilizes a pragmatic approach in arriving at the key locations of inspection on an oilseed processing line. This is important to allow for a basic understanding of critical control points and areas that may be inefficient, hence with potential losses along the chain and in this case prone to quality degradation. The study thereby develops a baseline for further research and development of automation technologies by systematically detailing these inspection criteria. The developments will help in attaining improvements both in accuracy and effectiveness in such procedures.

Thus, the automation of processing for oilseeds is quite a crucial need considering that most of the traditional methods applied are time-consuming, and highly unproductively effective. Technologies in this domain could significantly improve the operational efficiency of an organization, minimizing human error and increasing productive output to boost competitiveness in the volatile marketplace. Hence, in conclusion, the inquiry into the initial research question serves two purposes. This work fills an important gap in existing literature from the point of view of intellect, since it is the first systematic analysis of oilseed processing after due regard to the importance of the latter part of industry and opens new prospects for autonomous technologies, pinpointing the essential segments which can be subject to automation. This thesis will also be a dual-specific contribution to knowledge in an academic sense, where there is assurance of the pragmatic framework that industry players will adopt in guiding the technological adoption toward more efficient, safe, and economically viable oilseed processing operations.

RQ2: Which autonomous inspection technologies are potentially integrable into oilseed processing?

This research question has successfully tried to find and establish the possibility of embedding autonomous inspection technologies-UGVs and UAVs-into the oilseed processing industry. It was observed that UGVs and UAVs could provide a significant improvement in the productivity of plant operation by also ensuring a safe work environment for humans. UGVs have the capability to travel through constricted spaces and perform ground tasks that are very labor-intensive, making them highly appropriate for ground-based inspections. On the other hand, UAVs prove to be especially suitable for interventions in inaccessible places and inspections at height, thus reducing the risks associated with human exposure. At the same time, these technologies also meet high standards of safety and operation that are demanded in this oilseed-processing industry. These will result in radical improvements in traditional practices based on reductions in downtime and labor costs and improvements in data accuracy and decision-making from these emerging uses of UAVs and UGVs. This thesis's current results show large payoffs from using autonomy in the oilseed sector in terms of envisaged safety and efficiency improvement in the operations of this complex industrial setting.

RQ3: What are the assessment criteria for selection of applicable autonomous inspection technology(s) in the oilseed processing industry?

This research question answers toward the finding of relevant autonomous inspection technologies in the oilseed processing sector and articulates a set of essential criteria. This framework has been developed through more than 10 interviews at Cargill as a part of case study. Assessment criteria necessary for making well-informed decisions are Usability, Financial Viability, Safety Standards, Operational Efficiency, Legal and Regulatory Compliance, Technical Proficiency, and Technological Maturity. These criteria encompass both the urgent and strategic requirements of the industry, guaranteeing that technologies not only smoothly incorporate into current procedures but also correspond with long-term operational objectives.

The significance of intuitive interfaces and minimal training requirements is underscored by *usability*, which is essential for rapid adoption and integration into everyday operations. *Financial viability* analysis considers both the initial capital outlay and continuous operational expenses, promoting technologies that provide enduring financial advantages. *Safety standards* are of utmost importance, necessitating technologies to adhere to rigorous industry-specific procedures to guarantee the safety of workers and the integrity of operations.

Operational Efficiency is assessed by quantifiable measures such as reducing downtime and ensuring inspection accuracy, which have a direct impact on yield and output quality. Adherence to *legal and regulatory compliance* guarantees that the chosen technologies conform to both national and international standards. *Technological Maturity* ensures that only tested and proven effective technologies are considered for deployment, while *Technical Capability* focuses on the adaptability of technologies to diverse environmental conditions within oilseed processing.

A pairwise comparison questionnaire with 10 respondents identified the priority and preference of the criteria in the selection process of autonomous inspection technologies within the oilseed processing sector. The underlined most significant factor was found to be *Safety Standards*. On the opposite side, *technological maturity was ranke*d least in priority, meaning it is preferable to give up the maturity level of technology for other six set of criteria.

RQ4: How can an autonomous inspection technology selection approach be systematically developed and validated for the oilseed processing industry?

This research question aims to design a systematic assessment approach for selecting the optimal autonomous inspection technologies to use within the context of oilseed processing, which applies to Cargill's context. It was in the "second diamond" of the design project approach based on the 'develop and deliver' stages. The process underwent critical literature review of the existing selection methodologies for current technology, captured the MCDM techniques and adapted into an eight-step approach starting from project initiative to implementation plan. The process elements in between the steps are also proposed in the approach. It can be concluded that stakeholder involvement plays in the decision-making processes within the oilseed industry, as it has complexities in operations. The adaptation and modification of process elements from established model in the literature have shown that activities such as team formation, initial meetings, interviews, and expert consultations are essential for a robust decision-making approach. These elements improve the clarity, explicitness, and manageability of the decision-making process, making it easier to implement and follow. Importantly, the inclusion of stakeholders not only facilitates a valuable feedback mechanism but also ensures that the decision-making process is comprehensive and inclusive. The findings underscore the necessity of structured stakeholder engagement, highlighting its significant impact on the effectiveness of decision-making in complex industry settings.

The methodology has been then validated with extensive case study at Cargill to check whether the proposed methodology was working effectively and practically viable. This real application was well planned in conjunction with the procedural flowchart of oilseed storage segment of their operations, highlighting the need for improved inspection methods and an optimism for employing new inspection technology. One of the steps were identifying the six use-cases and how technology can be useful for monitoring conveyors, day tank, seed cleaning equipment, tunnel area and asset integrity of all the buildings and warehouses.

For the next step of technology identification, Elios 3, Intel Falcon 8+, Taurob Inspector, Groundhog Pro, and ANYmal were chosen. They were reviewed on terms of seven criteria deduced from empirical data retrieved from interviews with experts from Cargill to ensure that this systematic assessment approach was realistically related to actual industrial needs and conditions.

These were then integrated with the AHP into this selection decision, which was Elios 3; it significantly surpassed its alternatives because of the capacity to work with constraints and under complex conditions, therefore more suitable for the operation challenges at Cargill. The developed business case identified important critical areas of technology application and highly emphasized the need to identify technologies that are capable of safely and efficiently managing inspection of hard-to-access areas for reducing the risks and improving the reliability of the technologies at work.

This research illustrated was well-thought-out, assessment-based procedure for the choice of technology which was conceptualized and applied efficiently for this oilseed processing industry. This validation at Cargill confirmed the methodology in relevance and performance, constituting a milestone in the adoption of active inspection technologies.

In conclusion, the design objective of this thesis—*"To develop an assessment approach that supports strategic decision-making for industry leaders in the selection of optimal autonomous inspection technologies in oilseed processing"*—has been effectively fulfilled. The approach described here utilizes an effective multi-criteria decision-making framework to methodically direct the assessment and selection process, ensuring that each technology is carefully examined based on important operational and strategic criteria. The evaluation methodology was carefully developed by combining theoretical research with practical validation, which included conducting real-world tests in the oilseed processing setting at Cargill. The approach is based on actual data and firmly rooted in the concrete realities of the business, therefore guaranteeing its relevance and adaptability to the changing requirements of oilseed processing facilities. The established criteria for technology selection, which include usability, financial feasibility, safety standards, operational efficiency, legal and regulatory compliance, technical expertise, and technological maturity, contribute to a thorough foundation for decision-making. Thus, this guarantees that the chosen technologies not only suit the current operational circumstances but also correspond with wider strategic goals, so improving overall efficiency and safety.

This thesis provides a new and efficient tool for industry leaders to use in making well-informed decisions about the implementation of autonomous inspection technology. The next section will breakdown how generalizable this research is for other industries.

6.2 Generalizability of Study

The test of external validity of this thesis research can be assessed by the points stated:

Generalizability beyond Oilseed industry

Initially targeted at the oilseed industry, the potential for autonomous inspection technologies to be applied in the chemical and manufacturing industries-particularly in areas where safety and accuracy are key-is huge. Increased efficiency in inspection comes from assurance of personnel safety in dangerous environments and increased compliance with legislation due to the provision of accurate and traceable data. In showing their adaptability to complex and hard-to-reach areas, such systems do present a scalable and viable solution, one with implications for bringing operational excellence and competitive advantages across many other production environments. For first research question, where the inspection points and use cases were identified through a pragmatic approach kept the simplicity in the research and external validity beyond oil industry. However, for second research question, it is only limited to oilseed as other technology categories were such as underwater vehicles were filtered out due to applicability in offshore oil industry.

Empirical and Theoretical Validation

The design is empirically validated in the form of a case study on Cargill B.V. combined with a wide review of the literature currently available. This would increase the reliability of the thesis and the potential relevance of its findings to real-life similar situations. In a nutshell, although this dissertation takes its context from the oilseed processing industry, the findings regarding the autonomous inspection technologies, framework through which decisions regarding technology adoption are made, and increasing efficiencies in operations have wider generalizability. The findings can be generalized for other industries facing common challenges in the integration of new technologies, making the research an asset for both business leaders and technology management researchers. Therefore, the research related to systematic assessment approach will work as a skeleton, as its applicability is boundless to many other industries if it is modified with relevant industrial changes and needs.

6.3 Limitations

The systematic assessment approach was developed and validated, but it does have its limitations;

Considerations of Time and Resources in Technical Inputs

The methodology does not accommodate nor does it indicate the time and resources that will be spent to provide the much-needed technical inputs in implementing autonomous inspection technologies. It may affect both the feasibility and timing of the technology adoption. For the oilseed industry with different production units, a slight change in step 2 with change in scope can lead to significant changes, especially while iterating it back from step 4 or step 5.

Interview expert biases and sample size

Most of the methodology depends on interviews to elicit criteria weights, and they may add a few biases with respect to subjective views of the interviewed persons. Besides, by considering only one company, the case study restricts the base of data and does not represent a proper sample of the industry.

Confidentiality of inspections and use cases

Apart from lack of resources related to inspections in oilseed industry, the applications of autonomous inspections are very often clouded in secrecy, and there is a serious scarcity of openly published literature or case studies that make examples. This confidentiality might be an obstacle to deep comprehension and evaluation, limiting the possibility of generalizing the results or corroborating methodologies in diverse contexts of the industry itself. Accurate or generalized list of inspections points could have generated higher degree of exactitude in research, generating more rigorous output.

Criteria of Sustainability

The model disregards the rising relevance of environmental and sustainability concerns in technology selection, inherent in the assessment criteria of evaluation frameworks. It allows decisions to be made where potential consequences are not coherent with organizational objectives regarding sustainability or future regulatory requirements.

Generalizability beyond unmanned vehicle types

The broad terminology of 'autonomous inspection technology' only considers unmanned vehicles such as UGVs and UAVs, while the technologies can be extended to the sensors as well with their specific use cases. Therefore, the validity of this approach, even after various modifications needs to be tested and argued.

6.4 Recommendations

Modify and Test the Systematic assessment approach through different industries

The systematic assessment method proposed in this thesis needs modification and empirical examination within other sectors of the agribusiness industry to establish its appropriateness and soundness. The step-by-step approach needs a software application for enhancing usability of the approach within the company. These modifications allow further refinement of the methodology to suit the specific industry requirements, hence making the methodology even more relevant and enhancing usefulness in real-life applications. The future adaptation of this methodology in different contexts will provide insights into its adaptability and efficiency under various operation settings and therefore allow conducting an informed technology selection process that is considerate of specific industrial challenges and requirements.

Handling Technologies that are equally scoring on certain criteria

In cases where technological alternatives for a particular criterion score equally, it might be reasonable to add a sub-step to filter out or eliminate such criteria from the final decision-making assessments and calculations. This will simply reduce further steps in calculations, as it only focuses on what really differentiates the technological options.

Streamlining pairwise comparisons between criteria

In AHP, for pairwise comparison of preferences between the 7 criteria, a list of 21 questions were made as per the formula $n(n-1)/2$ (Saaty R. , 1987). Though there were only 7 criteria, the questionnaire was quite time consuming. Therefore, if there are more than 10 or 15 criteria, it is better to utilise other multi-criteria decision-making techniques such as Best-Worst method as it reduces the number of pairwise comparisons that need to be made by first simply identifying the best and worst criteria. All remaining criteria are then compared only with these two. In consequence, many fewer pair-wise comparisons are required (Rezaei, 2015).

Use case prioritization

In the expert interview for scoring technology alternatives with respect to criteria, use-case prioritization was considered as a sub-part of criteria *'operational efficiency.'* However, for future research, it is recommended to use it different criteria or addition another sub-step of ranking use case within the step three of identifying the inspection points. The prioritization will assist to decision makers to rather select technology which aligns that aligns with business objectives than just selecting it based its normal efficiency.

6.5 Discussions

6.5.1 Double diamond implications

The Double Diamond design approach, consisting of four stages—Discover, Define, Develop, and Deliver—has played a significant part in the thesis detailing the implementation of autonomous inspection technologies in the oilseed processing sector. Each stage made a crucial contribution, with the Discover phase commencing a comprehensive examination of oilseed processing, pinpointing deficiencies, and laying the foundation for subsequent inquiry. Nevertheless, this comprehensive strategy has drawbacks such as substantial resource consumption and a lack of specific attention to quick remedies. During the Define phase, the study focused on identifying precise and achievable objectives. This phase, however, posed a risk of premature convergence on answers and introduced subjectivity in designating crucial areas, which may potentially distort the study direction.

The Develop phase was dedicated to establishing a methodical selection process, modifying the methodology according to iterative input from industry partners such as Cargill. However, this phase faced difficulties in developing the required methodology and constraints in available resources. The way it was utilized there were no room for multiple iterations. The last stage, Deliver, showcased the pragmatic feasibility and efficacy of the strategy but encountered challenges in terms of scalability and reliance on external variables such as partner collaboration and market conditions. Notwithstanding these difficulties, the Double Diamond approach offered a systematic framework that enabled the implementation of technologies, ensuring congruence with both current operational requirements and future strategic objectives. This systematic and sequential method facilitated the connection between theoretical frameworks and actual implementations, which is crucial for guaranteeing that technical advancements are strategically robust and operationally efficient in the ever-changing oilseed processing sector.

6.5.2 Managerial Implications

This research provides a strategic implementation point of view for autonomous inspection technologies in the oilseed processing domain, which can be generalized to many other domains. For systemized implementation, the AHP is considered within the frame of the MCDM framework. This methodology will help managers balance operational needs with long-term strategic objectives in the assessment of technologies of interest against a wide range of criteria, including usability, financial viability, and safety legislation.

The emphasis on safety standards highlights a general managerial requirement present in several sectors with very high levels of operational hazards. It is through the deployment of technologically sound, safe standards that managers can enhance operational safety while proactively addressing regulatory compliance, decreasing legal liabilities, and increasing the culture of safety. This research elaborates more on the phenomenal potentials that autonomous technologies are likely to improve productivity with, for their further reduction of human errors. For managerial professionals, this would mean a move towards strategic investment in training and infrastructure capable of easier technology transitions and enhancements in continuous operation processes.

Besides, the proposed approach of assessment would be flexible to its application across industries for enabling responsiveness of managers considering continuous technological innovations and competitive challenges. In these sectors, the pace of transformation is radically fast, hence adaptability is a must. In the paper, it was identified that decision makers are ready to give up the technological maturity of technology for other criteria, but with industry 5.0 transition in this decade, with AI and systems focusing on high-tech human-machine interaction (Ghobakhloo, 2023), it will be imperative for managers to address training needs, and how preferences will be addressed in future for technology selection where the new technology with lower readiness level (Technological Maturity) would perform operationally better than proven technologies.

Finally, the prioritization of financial viability and operational effectiveness in the selection procedure provides a framework through which managers can justify investments in technologies. By focusing on the technologies offering tangible financial returns and an increase in operational efficiency, the managers are imparted with prospects for informed decisions that support fiscal objectives as well as operational efficiency. It provides a stronger, more thorough framework for industry leaders in making strategic-level decisions about the adoption of technologies. The result will be that the selected technologies support today's operational requirements and are aligned with broad strategic aims, improving overall efficiency and competitiveness.

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Appendix 1

1.1 Reflection of Master thesis

Upon reflecting on the past six months, during which I dedicated myself to my Master's thesis on the integration of autonomous inspection technologies in the oilseed industry, I have come to the realization that it has been a significantly enriching journey that has pushed me to develop my intellectual and practical abilities within a highly dynamic sector. The thesis commenced with an ambitious objective to rectify the deficiencies in conventional inspection methods in the oilseed industry, which are particularly error-prone and labour-intensive. The significant financial repercussions and impacts on product quality that these inefficiencies can cause made this initiative crucial. My goal was to create a strategic assessment methodology that would facilitate the selection of the most compatible autonomous inspection technologies by business leaders.

My investigation was organized around fundamental inquiries that sought to investigate the existing inspection procedures, identify potential autonomous technologies, establish pertinent evaluation criteria, and establish a methodical methodology for technology selection. The purpose of each of these inquiries was to not only direct my research focus but also to test my problem-solving abilities and promote a comprehensive understanding of technological integration in industrial environments.

Nevertheless, the journey was not without its initial challenges. The definition of the research's scope was a highly significant challenge. Initially, it was challenging to identify a focal area due to the oilseed processing industry's broad and intricate nature, as well as the rapid evolution of technology. The impact of my research was at risk of being diminished due to its broad scope, which necessitated numerous revisions to refine the research questions and objectives. Although the research methodology was robust, it also revealed areas that warranted critique. The exploratory approach, which employed interviews and case studies, was highly effective in acquiring nuanced insights. However, the double diamond model of design thinking, which effectively organized my research through its Discover, Define, Develop, and Deliver phases, may have restricted the investigation of alternative design methodologies that could have provided distinct perspectives and solutions. The framework of the study could have been potentially enhanced by a more comprehensive examination of design tools. Multi-Criteria Decision Analysis (MCDA) and the Analytic Hierarchy Process (AHP) were important during the development phase. Nevertheless, an additional criticism of my thesis could be the absence of a comprehensive functional analysis of systems engineering, which was hindered by the thesis's limited timeframe. This would have enabled a more comprehensive and technical examination of the system's functionalities and requirements. Furthermore, the MOSCOW method was implemented to prioritize a variety of research components, which was effective but not without its constraints. The thesis timeline's lack of strict time constraints allowed for the re-evaluation or relocation of specific priorities to better align with the industry's immediate practical requirements.

The case study conducted at Cargill was particularly important and illustrated the practical applicability of my research, despite these critiques. Not only did this aspect of my work validate the theoretical approach, but it also underscored the pragmatic relevance of the study, illustrating the effective translation of theoretical research into real-world applications. The feedback from industry experts validated the potential impact and necessity of integrating autonomous inspection technologies to improve the efficiency and accuracy of the oilseed industry.

In summary, my Master's thesis journey was characterized by both triumphs and obstructions. however, it ultimately cultivated a deeper understanding of the nuances of technology integration in industrial environments. It has equipped me with the necessary skills to pursue a career that is situated at the intersection of research and practical application. I am eager to continue my exploration and make a meaningful contribution to the advancement of industrial processes through innovation. This experience has instilled in me a strong appreciation for a disciplined yet adaptable approach to research and problem-solving, enabling me to thrive and adapt to a technological landscape that is constantly changing.

1.2 Reflection of Management of Technology (MOT) Courses

There were many courses in the Delft University of Technology's Management of Technology which were foundations of this Master thesis (MOT, n.d.);

1. MOT2313: Research Methods:

The research methods course influenced my Master's thesis as it equipped me with essential skills to define a research problem, set clear objectives, and develop a theoretical framework. Through the course, I learned how to operationalize concepts and select appropriate research designs, which were crucial in examining the integration of new technologies in a traditional industry. This educational foundation allowed me to conduct rigorous quantitative and qualitative analyses, ensuring the reliability and validity of my findings as I proposed and validated a new course.

2. MOT1524: Leadership and Technology Management:

In my Master's thesis on integrating autonomous inspection technologies within the oilseed industry, I drew upon concepts from the Leadership and Technology Management course, specifically focusing on technology management. This course equipped me to understand and address the challenges of technology selection as a fundamental aspect of technology management, aligning these decisions with broader business strategies to enhance organizational performance. Other than syllabus, the course also introduced to other research articles. One of them was related to transformational leadership, and it led concept of design thinking which is again a base of this thesis.

3. MOT1452: Inter and Intra organizational decision-making:

In my Master's thesis on integrating autonomous inspection technologies in the oilseed industry, I leveraged theories and strategies from this Decision-Making course. It deepened my understanding of practical decision-making processes and management of various stakeholders, which was critical for evaluating and selecting the appropriate technologies in a complex industrial context. This alignment of coursework with my thesis allowed me to effectively analyze and navigate the multifaceted decisions required in technology integration. Now that I look up the approach I proposed, it somewhat relates or inspired by ProAct approach of decision making. The acronym "ProAct" stands for Problem, Objectives, Alternatives, Consequences, and Tradeoffs (Decision Making Model, n.d.). It guides users to systematically evaluate these elements for strategic decisions, which was like the systematic approach developed in this research.

4. TUD4040: Joint interdisciplinary Programme:

This project experience at Schiphol Airport, where we utilized the double diamond design approach, directly informed my Master's thesis on autonomous inspection technologies in the oilseed industry. The project reinforced my skills in criteria selection and managing trade-offs, processes crucial both to the course and my thesis. This alignment enabled me to effectively integrate similar methodologies and decision-making frameworks, ensuring a comprehensive approach to aligning technological solutions with operational needs.

5. MOT201A: Preparation of Master Thesis:

The course prepared me for the thesis journey by teaching me how to identify both scientific and practical problems. It guided me in conducting an independent literature review to pinpoint knowledge gaps, which was pivotal in formulating a research question that was both scientifically robust and socially relevant. Moreover, the course emphasized creating a rigorous research design, a skill that I applied to structure my thesis methodically. Additionally, the ability to familiarize and apply Management of Technology (MOT)-relevant research methodologies directly influenced my approach, enabling me to tackle the complex issues within the oilseed industry with precision and academic rigor.

Appendix 2

2.1 Interview Guide

- Preliminary interview questions for defining scope of case study and initial interviewee list

  1. What exact regions Cargill is looking for new Autonomous inspection technologies?

  2. Why the existing solutions cannot to be implemented the business case scope?

  3. Which Cargill employees you would suggest for further interviewees?

1) General Process and Hazardous areas in plants/process
Objectives: 1) Understand the overall process flow and operations within the Cargill plants. 2) Explore the identification and management of hazardous areas or processes within the Cargill plants.

Questions:

- *Can you provide an overview of the primary processes involved in the operations of your (Storage/preparation/extraction/refinery) department?*

- *Are there any hazardous areas or materials in the processes which you encountered within the Cargill plant? If yes, how those areas are currently managed to ensure safety?*

- *(Extra Que/followed Que) Have there been any incidents or near-misses related to hazardous areas or processes in the past?*

2) Types of Inspection, the regions to inspect and difficulties associated with human Inspection.
Objectives: 1) Identify the types of inspections conducted and the specific areas or spots targeted within the plant which can be automated. 2) Understand the challenges and limitations of human-based inspection methods currently employed at Cargill.

Questions:

- *What types of inspections are currently performed within the Cargill plant?*

- *Are there any challenges or limitations associated with inspecting certain areas or equipment within the plant? If so, what are they?*

- *What are the limitations you encountered during human-based inspections within the plant?*

3) Need of Autonomous technologies and Criteria required for selection of technologies
Objectives: 1) Assess the rationale and perceived benefits of integrating autonomous inspection technologies into the operations of the Cargill plant. 2) Explore the criteria and considerations involved in selecting suitable autonomous inspection technologies for implementation.

Questions:

- *What are the driving factors behind the interest in implementing autonomous inspection technologies at Cargill? If implemented, what would be the challenges associated with it?*

- *What specific areas or equipment you would expect to derive from the adoption of autonomous inspection technologies?*

- *What are the regulatory challenges associated with certain areas for implementation of autonomous technologies?*

- *What core factors/criteria are considered when evaluating and selecting autonomous inspection technologies for the Cargill plant?*

2.2 Interviewee list and information

The table 10. shown below provides a structured overview of interview participants from Cargill, detailing their roles, locations, industry experience, and interview durations. It lists eleven participants, each with a unique designation, such as Continuous Improvement Senior Supervisor, Reliability Engineer, and Smart Manufacturing Robotics Engineer, among others. The table indicates a geographical diversity with locations spanning the Netherlands (NL), the United Kingdom (UK), France (FRA), the USA, and Canada (CAN). Participants' industry experiences ranges from over two years to over thirty years, highlighting a depth of expertise within the company. Interview durations vary, from as brief as 15 minutes to as long as 60 minutes, reflecting the different scopes of discussion expected with each participant.

Interviewee (Cargill)	**Designation**	**Location**	**Industry experience**	**Interview Duration** (in mins)
Participant 1	Continuous Improvement Senior Supervisor	NL	>05 years	60
Participant 2	Reliability engineer	NL	>05 years	30
Participant 3	Smart Manufacturing Process Expert	UK	>10 years	60
Participant 4	Digital Operations Leader	NL	>20 years	30
Participant 5	Reliability Excellence Leader	NL	>25 years	45
Participant 6	Plant Director	FRA	>30 years	30
Participant 7	Senior Reliability Engineer	NL	>20 years	45
Participant 8	Engineering Manager	USA	>20 years	60
Participant 9	Quality Assurance Leader	CAN	>10 years	45
Participant 10	Smart Manufacturing Leader	NL	>15 years	15
Participant 11	Smart Manufacturing Robotics Engineer	NL	>02 years	30
Participant A	Project Manager	NL	>07 years	60
Participant B	Smart Manufacturing Leader	NL	>15 years	60

TABLE 11. INTERVIEWEE LIST AND INFORMATION

Appendix 3

3.1 Coding Interviews

From the coding performed on Atlas software, these initial codes were generated. Later, the themes were generated out of these codes, to convert sub-criteria to main 7 criteria. These were the initial codes for criteria; hence the nomenclature or titles of codes were refined later. Both figures are given below.

Name	Grounded
Adaptive Environmental Functionality	2
Challenging Terrain Accessibility	5
Compliance with National Standards	0
Contractual and Software Licensing Expenditure	1
Cybersecurity Assessment	3
Downtime Minimization	3
Ease of Use Evaluation	6
Ergonomic Design Standards	1
Explosion Safety Certification (ATEX)	3
Industrial safety	7
Inspection Adequacy	9
Interface Design	2
Legal Compliance Assurance	7
Manual process	1
Measurement Repeatability	3
Multi-Setup Compatibility	9
Operational Inspection Costs	11
Process interruption from conveyors	1
Reasons for not doing Auto-Insp for seeds	1
Sensor Integration Capability	5
Technology Investment Costs	
Technology readiness level (Tech Maturity)	

FIGURE 23 INITIAL CODES FROM ATLAS

Code Groups	
Advanced Usability	(4)
Financial Assessment	(4)
Industrial Safety Standards	(1)
Inspection Operational Efficiency	(4)
Legal & Regulatory Assurance	(4)
Technical Legitimacy	(4)
Technology Maturity Assessment	(2)

FIGURE 24 CODE GROUPS FROM ATLAS

3.2 Criteria description

The detailed visualization of all the finalized criteria and sub-criteria which were coded from interviews is shown below with the description in figure 24.

Criteria	Sub-criteria involved	Description
Usability	Ease of use evaluation	Evaluates how intuitive the technology is for end-users
	Ergonomic design standards	Focuses on physical interface aimed for reducing user fatigue
	Interface Design	Comprehensible user interface for facilitating smooth user experience
	Training requirement	Focuses on the extent of training or proficiency level required for users to operate the technology
Financial Viability	Contractual & software licensing expenditure	Cost associated with legal and software agreements
	Operational inspection costs	Assessment of costs involved with inspection operation and maintenance
	Technology Investment cost	Total capital investment required technology deployment (rent/buy)
	Training requirement	Focuses on the extent of training or proficiency level required for users to operate the technology
Safety Standards	Industrial Safety	Ensuring technology complies with oilseed industry's safety standards to prevent accidents and operational mishaps
Operational Efficiency	Downtime minimization	Measures the technology ability to minimize idle time
	Inspection adequacy	Measures the quality of inspection operation including its accuracy and speed
	Measurement repeatability & reproducibility	Repeatability: Consistency in measurements across multiple usage, Reproducibility: Assessment of consistent measurement yield via multiple operator
	Multi-Setup Compatibility	Assesses whether technology can inspect multiple assets (versatility)
Legal & Regulatory Compliance	Compliance with National standards	Technology's relevance with respect to national laws and regulations
	Cybersecurity Assessment	Technology's resilience against cyber threats
	Explosion Safety Certification (ATEX)	Certification of the technology for safe usage in explosive environment
	Industrial Legal compliance	Technology's compliance to legal requirement of oilseed industry
Technical Capability	Adaptive Environmental Functionality	Ability of the technology to be weatherproof
	Challenging Terrain Accessibility	Technology's capability to withstand difficult terrains such as confined spaces, tunnels, steep inclines and other uneven landscapes
	Explosion Safety Certification (ATEX)	Certification of the technology for safe usage in explosive environment
	Sensor and Software Integration Capability	Ability of the technology to seamlessly integrate with multiple existing or new sensor technologies
Technological Maturity	Technology Readiness level (TRL)	Measurement of technology's maturity via various levels (e.g TRL1 : Concept phase, TRL6: Prototype demonstration TRL9: System proven)
	Sensor and software Integration Capability	Ability of the technology to seamlessly integrate with multiple existing or new sensor and software systems

FIGURE 25 CRITERIA DESCRIPTION

Appendix 4

A detailed table of all the interview quotes and codes are attached.

Quotation Content	Codes
Well, does the technology give you measurement data for the to prevent the failure mode that you're trying to prevent or detect the detect the anomaly or the, you know, out of condition?	Inspection Adequacy Measurement Repeatability
So the drones are what we use drone with cameras and drones with sensors, infrared.	Sensor Integration Capability
if it can do multiple tasks, that's a benefit. Yeah, but it's if if I want to inspect for corrosion, yeah, then I need AI, need a visual camera.	Multi-Setup Compatibility Sensor Integration Capability
criteria is like cost.	Operational Inspection Costs Technology Investment Costs
Like obviously these drones and the technologies are somewhere connected to some servers, which sometimes can, cannot be in control of Cargill.	Cybersecurity Assessment
So it's it's still the it's still the a government official or government body that's that trolls all access to ports and they won't they won't let you fly a drone around in a port unless you get special permissions.1:07:06You gotta apply for a, you have to have a pilot's license, you have to apply for permission.	Legal Compliance Assurance
The inspection one of the things that comes before inspection is cleaning.6:37Cleaning of the silo, cleaning of silo or tanks, because we are talking about oil tanks, we are talking about grain silos.	Manual process
What I see is the the the the non collision feature I think is a is an important one also when we are talking about the grain size laws and things like that.3:51So safety can be a criteria.	Industrial safety
Well, always you should consider the cost	Operational Inspection Costs Technology Investment Costs

So we want something that you don't need a huge development to be done to be adapted to this particular silo because you want to use it in the same plant in a silo which is slightly smaller.	Multi-Setup Compatibility
something like a versatility as well.5:38I mean, if you like something like one, I mean, mostly the decision makers want one tool to be used on multiple occasions or at multiple places.	Multi-Setup Compatibility
ideally should be able to operate on not perfect environment.	Challenging Terrain Accessibility
we will be interested in in buying something which is already proven.	Technology readiness level (Tech Maturity)
So now the technology is automatic sampler, which takes the samples from the truck, you know, then the the the seeds goes to to our laboratory and then they check in the laboratory.	Technology for Seed sample inspection
we don't need like a CCTV camera or something or like something to inspect the moisture content 24/7.20:02We don't need that.20:03We just do that in the entrance.20:07And Yeah, unloading time and then we leave it.	Reasons for not doing Auto-Insp for seeds
First of all, if the technology can avoid that we need to build a scaffolding or we can avoid that we need to have an entry, that would be great.	Challenging Terrain Accessibility Ease of Use Evaluation Industrial safety Operational Inspection Costs Technology Investment Costs
And the other one is on technologies is that if you want to use technology, you need to understand what legally is needed.23:28So, so we so we need to have a conversation at the legal departments that if we can use those technologies and if those are good enough to get a legal sign off that we did the right inspection.	Legal Compliance Assurance
quality of the data.	Inspection Adequacy

It should be proven	Technology readiness level (Tech Maturity)
That could be a criteria to also how easy can we use the data	
OK, you can make a distinguish between explosion proof or not, you know, because some things you are in the next scenario, you need that explosion proof, you know, yeah, the 8X certified.	Challenging Terrain Accessibility Explosion Safety Certification (ATEX)
But we're not going to implement technology or something which we can only use as one asset.	Multi-Setup Compatibility
The first thing is the requirements, right?31:19Does it do what I need it to do?31:21And we're always assuming I want, I have a problem that I need to solve	Inspection Adequacy
The second thing is the cost, right? That is always a consideration with all businesses. And most importantly, if you're solving a problem that has to do with your operations, there should be a return on invested capital.	Operational Inspection Costs Technology Investment Costs
looking at a new technology, I think those are the main things, Saket.34:42OK, Obviously there's smaller things that you need to check, like user friendliness, usability, ergonomic stuff, ergonomic stuff, or service agreements with a partner.	Ease of Use Evaluation Ergonomic Design Standards
Like, yeah, do you know the maintenance part of it and the upkeep if it breaks?35:00Do I have a, a, a good agreement with this company to repair its spare parts and things like that?35:06Right.35:06But that comes a bit further down the line if you meet the first things, yeah, your procurement team or your strategy team can work on the vendor agreements to get better support, right.	Spare part availability
It's I think a standard kind of scale of, so you can ask a vendor in the tech maturity scale, where do you see your product being today?	Technology readiness level (Tech Maturity)
I wouldn't only limit it to cybersecurity 'cause it's not always that we're gonna be under an attack from hackers, cybersecurity, but it's also general IT connectivity.	Cybersecurity Assessment
So for your conveyors, and I know conveyors a bit, your problem is that they breakdown often and I need to stop my process and it's dangerous putting people in that position.	Process interruption from conveyors
We're not going to use it down the stairs when there's no one there to supervise and things like that.26:40So there, that's the environmental health and safety part of it.	Industrial safety

So that's really important to not necessarily identify all the details of the problem that it might solve, but the main metrics, yeah, that this technology would help us improve.41:38And that might be efficiency, safety and productivity, less downtime.	Downtime Minimization
The other thing that we didn't talk about, and it will come into play is how much money am I paying third party companies for contracts to do things for me	Contractual and Software Licensing Expenditure
assess whether the technology is capable of doing that. So if, for example, I want to check the temperature, but my technology doesn't have a temperature sensor, then I don't want to do it.45:39Or if, for example, I want to check with a camera, but my technology doesn't have a flashlight and it's in the dark and I can't see anything, I don't want to do it.45:48So you need to check if the inspection that you want to do can be successfully carried out with the technology that you're trying to introduce.	Sensor Integration Capability
Do we also consider that one solution is solving or it can implement or it can be implemented to different setup?- Absolutely. So it's more versatile.	Multi-Setup Compatibility
So if it's as simple as doing like a video game, remote control, taking the robot and putting it in there with basic training and we can train X amount of people to do it.48:31Yeah, You need to define maybe how many people should be trained and doing it.	Interface Design Training requirement
o if we have very well business requirements, we call them for this, for this solution and, and there is a robust way of, of measuring it. So it's repeatable, reproducible, etcetera. That will be a, a key factor.	Inspection Adequacy
the second thing would of course be the cost versus value.	Operational Inspection Costs Technology Investment Costs
So is it, do we have multiple people who can work with this solution if I call it like that and a mobile solution?8:29So, so that is one the user friendliness and then the the robustness.	Ease of Use Evaluation Inspection Adequacy Training requirement
Is it easy to drop down the stairs and then fall into pieces?8:41Well, is it capable to to go on the stairs or or to go everywhere?	Multi-Setup Compatibility
And and then last but not least, but you already mentioned in interview is it's Atex Zone application, which is very limiting applications.	Explosion Safety Certification (ATEX) Legal Compliance Assurance
regulatory standards	Legal Compliance Assurance
So it has to not have the burden to recharge or it's like a like doesn't have a need a break that would be like the longest usage of it.	Ease of Use Evaluation Interface Design

So like a ground robot should also go around multiple floors in the plant, climb stairs and make its way through uneven surfaces.	Challenging Terrain Accessibility
Technology with ATEX certification can be criteria for explosive environment.	Explosion Safety Certification (ATEX)
So when it's raining, it should be working as well because the robot dog can't work outside if it's raining.	Adaptive Environmental Functionality
So use cases, multiple use cases exactly nobody thinks of.	Multi-Setup Compatibility
So it's more which ones are our biggest issues today?16:18Does the technology solve that problem that we have today, right?16:23Because at the end we are we're not looking for this technology.16:25We are looking more for the solution that we try to solve or the problem that we try to solve, right.	Inspection Adequacy
'if we want to go for an external inspection, it's harder if the airport is nearby.'	Adaptive Environmental Functionality Legal Compliance Assurance
In this case, instead of building a scaffold and measuring the wall thickness from the exterior, I can give you this alternative because I know how it works and I will provide the same, the same results in a faster, quicker, cheaper way.	Downtime Minimization Operational Inspection Costs Technology Investment Costs
I mean, plenty of factors affect or could be could be in one city , but not in another because of airport, right or or that's a fair point as it depends on the legal.	Legal Compliance Assurance
Sometimes with the new technology, the risk of a confined space is reduced, but then cost is three times higher.So it's not a sensible option.	Operational Inspection Costs Technology Investment Costs
So if if this one is helping, for example, when we are using the Elios, it's very convenient for indoor for the silos because we avoid building all the scaffold, we avoid cleaning the the bottom.	Downtime Minimization Ease of Use Evaluation Operational Inspection Costs
Autonomous for me is also the online sensor for vibration monitoring.29:11They have sensors remotely working every day making a photo of the of the vibration monitoring that is helping us a lot.	Sensor Integration Capability
Mobility in the plant.	Challenging Terrain Accessibility Multi-Setup Compatibility

So it should be safe to operate.21:09It should prevent people, it should prevent pedestrians to be hit by the device.	Industrial safety
So we, we, we do a lot of vibration analysis, vibration as part of our asset inspection.	Sensor Integration Capability
nd that cost needs to be put against the current cost of of manual inspection, right.	Operational Inspection Costs
So the the the business case so current cost versus new cost and and compared to the needed investment, right.26:30That is a huge criteria the amount, right,	Technology Investment Costs
I think it's important that the measurement is repeatable.38:16So if you have exactly the same situation that and you do the measurement 10 times that you get 10 times almost the same result.	Measurement Repeatability
Yeah, the ease of use but in the end, the goal is of course to have more reliable data.Yeah, more more frequent data, right. And the data or the, the result, the outcome of the inspection, Yeah, should be fast enough between the, the, the time where you measure it and where you get the result, OK, That you can actually still have time to do something about it, right?	Ease of Use Evaluation Inspection Adequacy
Now, of course, the the goal is to have as least as possible robots, Because every time you add another robot, you need to maintain it.	Multi-Setup Compatibility
The cost for the actual autonomous system, Yeah.44:37 because if the cost will be more than you're actually going to save with the inspection, then you need shouldn't need to do it, right.	Operational Inspection Costs Technology Investment Costs
So the usability, right, If you need a very specialized person to implement these kind of technologies, then that will cost more, right?	Training requirement
So that to me that's probably the most important thing is the quality and the and the value that the technology would deliver.27:17Obviously safety is a huge concern.	Industrial safety Inspection Adequacy
If it's, if it costs two times as much money, then you're never gonna be able to sell that to the organization	Technology Investment Costs
But the technology should have an ability to repeat, Yeah.28:21Repeatability, yeah, that's pretty critical.	Measurement Repeatability
I mean, there's always, I mean, I don't know if there's anything that's completely secure from cybersecurity nowadays.	Cybersecurity Assessment

if somebody had a a score and a table and said, yeah, this has already been proven and it works in these environments and these conditions, yeah, that would be that would be valuable rather than us spending the time and the money and the resources to improving.	Technology readiness level (Tech Maturity)
We run into challenges where we can have the technology available and we can use it in country1, but for us to use the same technology in country 2 is a challenge because of different laws, So, legal and the regulation stuff."	Legal Compliance Assurance

Appendix 5

Questionnaire

Conducted a questionnaire to assess the relative importance of seven criteria by comparing them pairwise, resulting in 21 comparisons. Ten Cargill employees participated, rating their preferences for each pair. Their responses were averaged to create a pairwise matrix. The participants received the survey details via email and submitted their choices through a Microsoft Forms link. The survey used a modified paired comparison scale, allowing participants to select between two options at a time to rank their preferences.

Questionnaire Guide input for Thesis Research

Welcome! This questionnaire involves a series of pairwise comparisons between different selection criteria for autonomous inspection technologies. Please rate the relative importance of one criterion over another based on their significance in selecting autonomous inspection technologies. All your responses will be anonymous.

Description of all Criteria for Autonomous Inspection Technology Selection

C1: Usability: Evaluates how user-friendly and accessible the technology is for its users. It includes assessments of Ease-ofUse Evaluation, Ergonomic Design Standards, and user interface design

C2: Financial Viability: Considers overall costs associated with Technology deployment.

C3: Safety Standards: Encompasses compliance with safety regulations to prevent accidents and injuries.

C4: Operational Efficiency: Assesses the technology's efficiency. Includes Downtime Minimization, Inspection quality and its Multi-Setup Compatibility

C5: Legal & Regulatory Compliance: Ensure the technology meets all applicable legal and regulatory requirements including Cybersecurity Assessments.

C6; Technical Capability: Evaluates the technology’s Adaptive Environmental Functionality, Difficult landscape Accessibility, sensor capability and ATEX certification.

C7: Technological Maturity: Evaluating the Technology Readiness Level (TRL)

(For example- TRL1: Concept phase, TRL6: Prototype demonstration TRL9: System proven**)**

Instructions:

1 means that both criteria have equal importance.

3 indicates that one element is slightly more important than the other.

5 means one element is very important than the other.

7 one element is highly important than the other.

9 means extremely important.

2, 4, 6, and 8 serve as intermediate values

1. Which option has your preference? **C2 (Financial Viability) and C1 (Usability)**

*

1	2	3	4	5	6	7	8	9

Appendix 6

6.1 Sensitivity analysis

Sensitivity analysis was carried out on Spice logic software for AHP which is represented below.

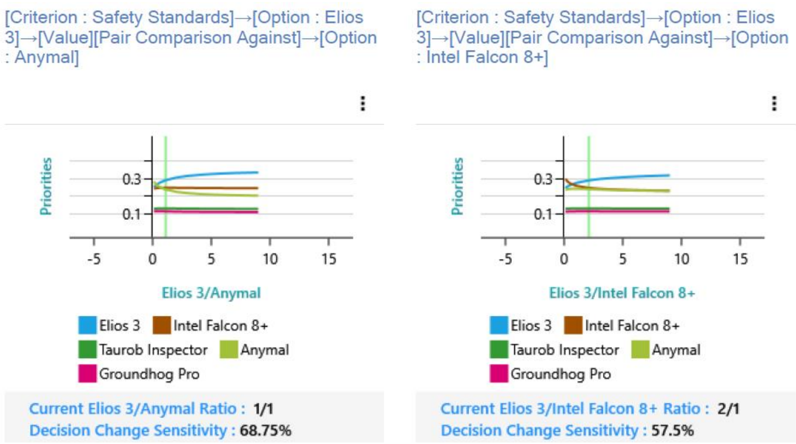

FIGURE 26. SENSITIVITY ANALYSIS 1

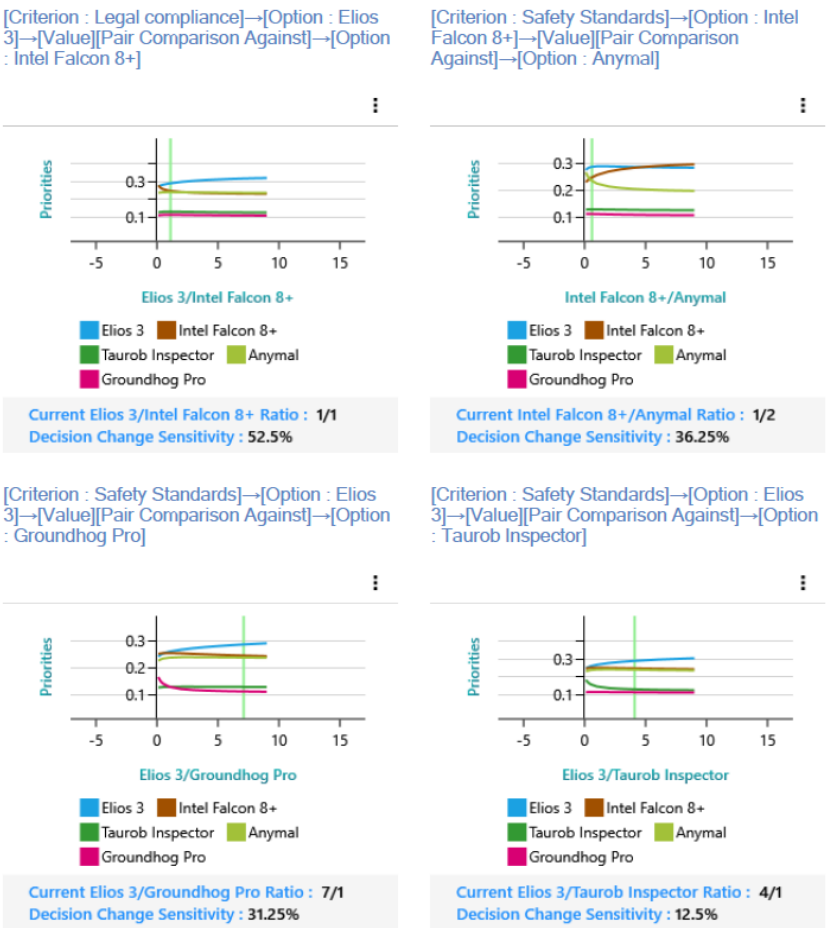

FIGURE 27. SENSITIVITY ANALYSIS 2